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Vol. 197 FEBRUARY, 1924 No. 2

A PRIMARY STANDARD OF LIGHT, FOLLOWING THE PROPOSAL OF WAIDNER AND BURGESS.

BY

HERBERT E. IVES, Ph.D.

Research Laboratories American Telephone and Telegraph Company, and Western Electric Company, Incorporated; Member of the Institute.

I. INTRODUCTION.

(*a*) *Discussion of Existing Standards.*—The problem of producing a satisfactory primary standard of light is one which has engaged the attention of photometrists from the earliest days of the science. In spite, however, of an enormous amount of work a really satisfactory standard has not as yet been produced. In fact, rather little attention has of late been given to the problem; there is, indeed, promise that the need for a specific standard of *light* may ultimately be obviated by the establishment of satisfactory *radiation* standards and the accurate correlation of the photometric with the radiometric units, through the exact specification and determination of the "mechanical equivalent of light." [1] Nevertheless the importance of possessing a reliable standard for the scientific and technical measurement of luminous energy is great enough to warrant serious study of the problem. What is required is in general some source of luminous energy whose construction can be accurately specified and reproduced, and whose luminous output shall be fixed by the specified construction with a definiteness comparable with the accuracy attainable in the best methods of photometric measurement.

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In order to meet the general requirement in a practical manner a primary standard should have certain characteristics of which the following may be selected as most important:

First: The specification of its construction and use should be as simple and unambiguous as possible. This does not mean, however, in the present state of the science of photometry, that the standard should be of such simplicity as to permit of its being quickly or cheaply reproduced in any laboratories outside of the chief standardizing institutions. Neither is it necessary that the value of the standard shall determine the photometric *unit*. What is desired is an accurate reproducible *fixed point*. It is desirable, from the scientific standpoint, that the standard should be related as directly as may be with other standards and constants of physics. Its specification should preferably be in terms of simple physical constants rather than in terms of chimney size, weave of wick, or the number of holes in a peculiar design of burner.

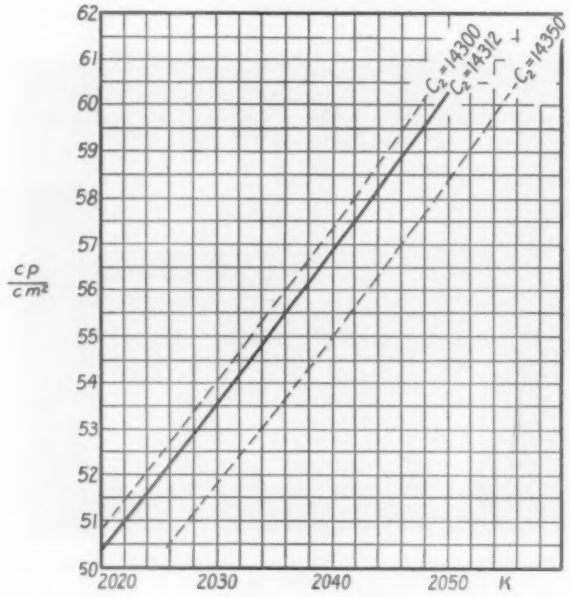
Second: The standard should be unaffected by conditions which are difficult or impossible to control, such as the state of the atmosphere.

Third: The standard should be of such form and yield light of such intensity and quality as to offer no serious impediments to the processes of photometric comparison.

At the present time the only primary standards which can lay claim to actual use are flame standards which are far from meeting the requirements just set forth. These comprise the Hefner lamp, the Harcourt pentane lamp, and the Carcel lamp. It was the hope of those who devised these lamps (or adapted an existing illuminant, in the case of the Carcel) that when the dimensions of the metal parts, the dimensions, material and form of the wick, and the composition of the fuel, were exactly specified, these flames would yield light of fixed and reproducible intensity. In practice, however, this hope has not been realized. Besides being affected to an extreme degree by atmospheric conditions, these lamps have not proved to be reproducible. At the present time the standard pentane lamp is a lamp of a certain serial number which is preserved in London; the standard Hefner lamp is actually a group of lamps, whose mean value for comparison purposes is preserved by incandescent electric lamps. Other Hefner and pentane lamps are intercompared with these master

standards and given certificates stating their true value. Thus the Reichsanstalt certifies as correct any Hefner lamp whose luminous intensity is within *2 per cent.* of the master standard. Pentane lamps made with the utmost care, burning the same fuel, in the same atmosphere, and operated by the same people, differ in candle-power by as much as 2 or 3 per cent. The maker of the National Physical Laboratory master standard was unable to make

FIG. 1.



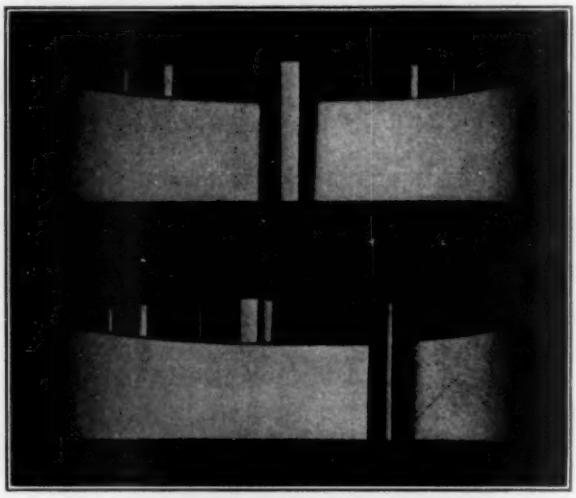
Calculated brightness of the black body near the melting point of platinum, using various values of C_2.

for the Bureau of Standards a pentane lamp duplicating the original in candle-power.

The specifications of these lamps are far from simple, especially in the case of the pentane and Carcel lamps, which are cumbersome and complicated structures, with innumerable opportunities for variations in materials, dimensions, and methods of fabrication which may result in considerable changes in the amount of light emitted. But even if the lamps could be produced to yield identical results under identical conditions, many additional specifications would be necessary. A standard atmospheric pres-

sure, a standard humidity, a minimum of atmospheric vitiation by the observers, and probably a standard temperature, must be specified. Where measurements cannot be made under these standard conditions (that is, practically always) large correction factors must be applied. The determination of these correction factors has been the subject of many investigations, which have been far from consistent. The discrepancy between the correction factors as determined by the Reichsanstalt and the National

FIG. 2.



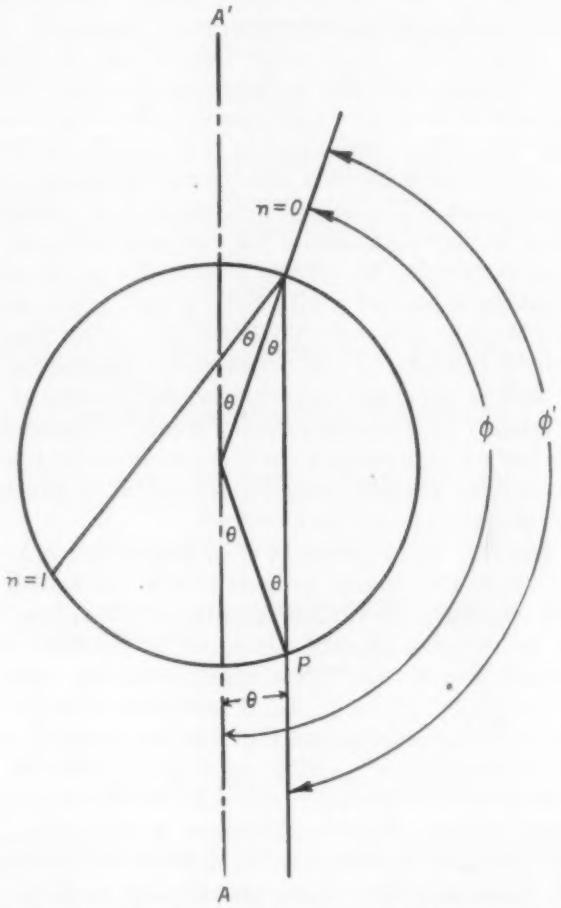
Photographs of silvered glass cylinder illustrating character of multiple reflections occurring in platinum cylinder black body.

Physical Laboratory was so great as to cause a difference of over 1.5 per cent. in the average corrected values of flame standards as measured at Washington in the summer. A thorough study of the methods of humidity measurement has reduced this source of error, but even so the necessity for the family of auxiliary measurements which must be made, incident to a candle-power determination, renders the entire specification of these flame standards discouragingly complex.

The Hefner lamp is redder in color than any illuminant in common use; it is of inconveniently low intensity (.9 candle-power) and is excessively subject to unsteadiness due to air

currents. The pentane lamp while whiter than the Hefner is still too red; its intensity (10 candle-power) is reasonably satisfactory. The Carcel, burning Colza oil, is the whitest flame standard, but

FIG. 3.



Section of cylinder with reflecting walls showing path of incident light beams up to second reflection.

the intensity is so variable in value from lamp to lamp, and during the period of burning, that it is of no real value as a standard.

In an emergency these flame standards, unsatisfactory though they are, would have to be relied upon to reëstablish the candle-

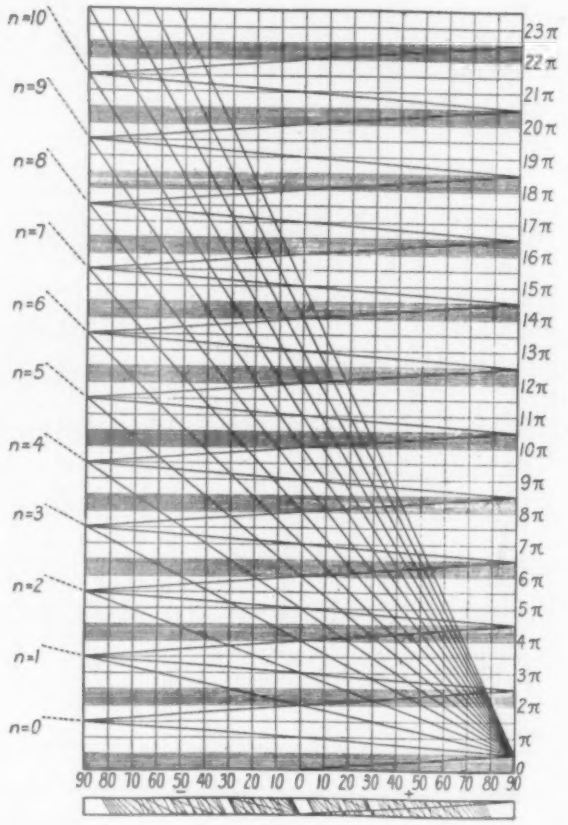
power scale, and by the careful application of the best determined correction factors would probably do it fairly well. At the present time, however, the real reliance for maintaining the standards underlying the lighting industries is placed upon a number of groups of carbon incandescent electric lamps which are preserved in the chief standardizing laboratories of the world. Carefully selected lamps of this kind, while they cannot be designed and constructed to give a desired candle-power, do have the characteristic when operated under simply specified electrical conditions of preserving their value comparatively unchanged over long periods of time, and of being entirely free from the influence of atmospheric conditions. By using the master incandescent lamp standards only very occasionally for the preparation of secondary or working standards, this scheme insures the maintenance of the unit of luminous intensity with only a very small drift, which should not become of significance until after many years. While this practical solution of the problem of maintaining the photometric unit is very satisfactory, for the present at least, the need for a really satisfactory primary standard remains. Underlying this use of incandescent lamp *maintaining* standards is the hope that a real standard may be developed to which the unit of luminous intensity may be anchored.

(*b*) *The Use of Platinum in Connection with a Standard of Light.*—One of the earliest proposals, and one which has been frequently repeated in various forms, is to utilize the metal *platinum* in the incandescent state, under specified conditions which would insure the reproducibility of the light emitted. Draper[2] suggested in 1847 that a standard of light would be furnished by the emission from a surface of platinum maintained at a known temperature; and it appeared in his time that the problem of fixing a temperature would be capable of easy solution. As a matter of fact, the two difficulties of ensuring a real, that is a clean, platinum surface, and of determining its temperature accurately, have been the greatest obstacles up to the present time in the problem of utilizing the uniquely favorable chemical properties of platinum, namely, its freedom from contamination by the atmosphere and its high melting and boiling points.

An important step toward meeting the difficulty of temperature determination was made by Violle[3] in his well-known proposal to specify the standard of light by the radiation from platinum

at its melting or freezing point. Violle's method of realizing this standard was to melt in a crucible a very large quantity of platinum the light from which passed through a diaphragm to the pho-

FIG. 4.

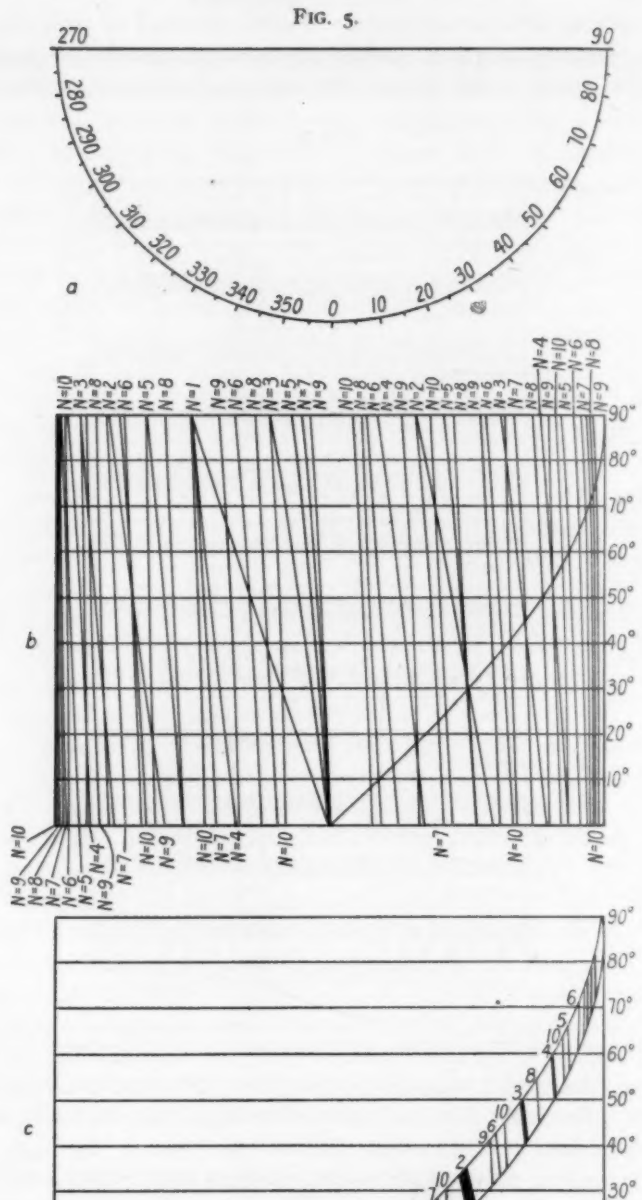


Position of reflected images of slit as the cylinder is rotated; angle of rotation given by ordinates, angular position of reflection by abscissæ, number of reflections indicated by n.

tometer. Siemens [4] proposed to simplify this procedure by observing the light from thin platinum strips heated electrically to the melting point.

The melting point of platinum, while its exact value is not even yet determined beyond all question, is nevertheless a very definite point in the high temperature scale, quite unaffected by any of

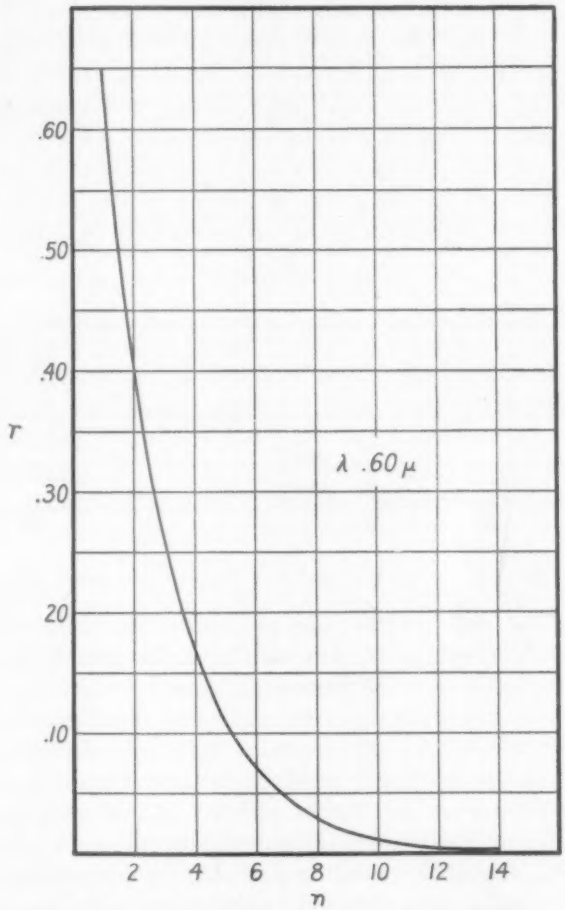
FIG. 5.



Reflected slit images as seen at various angles through (*b*) a transparent cylinder, (*c*) through a slit ten degrees wide.

the atmospheric conditions which are so troublesome with the flame standards. It would therefore seem probable that these suggestions, in which the platinum melting point fixes the tem-

FIG. 6.

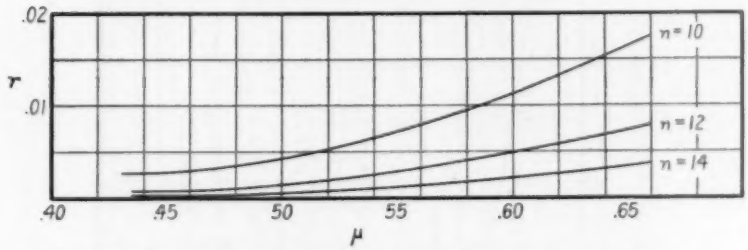


Reflected light, wave-length .6μ, after n reflections from platinum.

perature of the incandescent metal, would come close to making the platinum standards successful. These hopes have, however, not been borne out. Attempts to reproduce the Violle standard [5] have not duplicated the original published values within 25 per cent. Tests of the Siemens standard by Liebenthal [6] and by

Lummer and Kurlbaum [7] have not led to favorable results. Liebenthal, for instance, found in comparing the light of the platinum strip at its melting point with that of a Hefner lamp that his mean error of observation was about 3 per cent., whereas in comparing two Hefner lamps with each other it was about 1 per cent. He ascribed the greater error of setting in large part to the considerable color difference between the Hefner lamp and the melting platinum—the latter being considerably whiter. Lummer and Kurlbaum said that deviations in some 500 meltings ran to 10 per cent. or more. A major difficulty they encountered was the tendency of the strips to tear apart due to their weight, before the true melt took place. Experiments by Dibdin [8] along

FIG. 7.



Reflected light after 10, 12 and 14 reflections from platinum, at various wave-lengths.

the same lines indicated that the presence of particles of impurity on the surface of the metal—which would greatly increase its emissive power—were an important source of error. Petavel,[9] as a result of extensive experiments, found that the melting point was greatly affected by the nature of the gas used for the heating flame. Later it has been established that the emissive power of platinum undergoes an abrupt change at the melting point.[10] In consequence of the experimental difficulties and the unpromising results, attempts to utilize platinum in connection with the standard of light have been long since abandoned.

(*c*) *Black-body Standards.*—Almost simultaneously with the last recorded experiments on platinum standards of light, occurred the development of the theory and the practical realization of the *black body or complete radiator.* The fact that the radiation of the black body can be expressed by a rational formula, and that the radiation is similar in character to that of most artificial illu-

minants, attracted attention to it immediately as a possible solution of the standard of light problem. One important advantage of the black body is that the question of *surface* is eliminated, since the completely absorbing enclosure which is involved in the definition of the black body is both theoretically and practically of definite and reproducible character. A disadvantage of the black body is that with it, we must face the problem of accurate temperature determination, and for the purposes of a photometric standard the temperatures which would be suitable (in the neighborhood of 2000 degrees absolute) are beyond the range of any of the simpler temperature measuring devices such as thermocouples. Optical and total radiation methods of temperature determination are unsatisfactory for several reasons. The interval to be covered from the highest point definitely fixed by the gas thermometer (the gold melting point at 1336° K.) to the temperatures which would be useful is so great that the radiation constants would have to be known far more accurately than is now the case to assure the temperatures indicated being within the single degree or thereabouts, which, as we shall see, is necessary to fix a photometric standard. The actual points which could be so fixed would not strictly be *temperatures,* but points defined by total radiation or monochromatic radiation intensity intervals from the fixed point taken for reference, *e.g.,* the gold point; thus the determination of the "temperature" would itself involve a photometric or radiometric comparison, which, because of the large interval covered, could not be expected to compare favorably with the photometric accuracy attainable in the strictly photometric side of the problem.

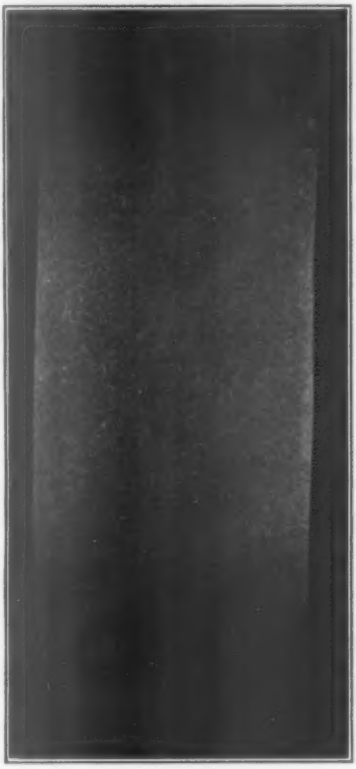
In order to avoid direct measurement of temperature, several methods of fixing the temperature by balancing one part of the radiation against another have been proposed. The most important of these is the proposal of Lummer and Kurlbaum,[11] which is that the radiator should be brought to such a temperature that the radiation transmitted through a cell of water of definite thickness shall bear a certain ratio to the total radiation. This method is claimed to fix the temperature so accurately that the light may be maintained within 1 per cent. The experimental technic is, however, of very great complexity, and nothing has been done with the idea since the original experimental study, which was carried out with platinum as the radiator.

(*d*) *The Suggestion of Waidner and Burgess.*—In 1908 Waidner and Burgess [12] made a suggestion which incorporated the most desirable features of the proposed platinum standards and of the suggested black-body standards. Their suggestion was that the standard of light should be *the brightness of a black body at the melting point of platinum.* In other words, they proposed using the definite point on the temperature scale fixed by the platinum melting point, but avoiding the unsatisfactory platinum surface by substituting a surfaceless black body. They suggested that this standard might be realized practically by immersing a hollow inclosure in a bath of molten platinum and measuring the brightness at the freezing point of the platinum. No attempt was made by them to carry out their very interesting suggestion.

(*e*) *Luminous Properties of a Black Body Near the Temperature of Melting Platinum.*—A very notable merit of the black body as a standard light source, which is preserved in the suggestion of Waidner and Burgess, is the possibility of calculating its luminous emission from constants and data derived from other fields of physics. The luminous emission of any radiating body is, in general, $\int L_\lambda E_\lambda d\lambda$ taken over the spectrum; L_λ representing the luminous efficiency or relative visual stimulating value of the radiation at wave-length λ, E_λ, the intensity of radiation, and $d\lambda$, the width of an infinitesimal monochromatic strip of radiation at the same wave-length. For the black body we have the well-established Planck radiation formula: $E_\lambda = \frac{C_1 \lambda^{-5}}{1 - e^{\frac{C_2}{\lambda T}}}$; for the luminous efficiency there is available the curve as determined by the present writer, which is in close agreement with several other recent determinations. This luminous-efficiency curve has been expressed algebraically in the form of a three-term expression, which may be combined with the Planck black-body equation to yield, by calculation, the luminous emission of the black body at any temperature. Upon carrying through the computations—for the details of which reference may be made to an earlier paper [13]—the data shown in Fig. 1 (full line) are obtained for the luminous emission of the black body in the temperature range from 2020 degrees to 2050 degrees absolute, in which the melting point of platinum is known to lie. The values of the black-body

constants used in this computation are 5.72×10^{-12} for σ, 14,312 for C_2. For the constant (m) relating practical luminous units with the rational ones (least mechanical equivalent of light) the value .00156 is used as determined from experiments as independent as possible of any choice of black-body constants. If

FIG. 8.



Side view of glowing platinum cylinder.

one of the most recent values for the melting point of platinum is taken, namely, 2037 degrees, this calculation indicates a value of 55.9 candles per square centimetre as the brightness of the black body at the melting point of platinum.

From the curves plotted in Fig. 1 we can easily learn the effect, on the brightness, of possible variations in the melting point—such as those due to impurities—and the effect, on the

computed result, of different choice of the black-body or luminous constants. Thus for the region in question one degree variation in temperature produces .65 per cent. variation in brightness. Consequently to establish the brightness to within ½ per cent., which is a reasonable goal for a photometric standard, *the melting point must not be in error by as much as one degree.* At the present time it cannot be claimed that the melting point of platinum is known accurately to within five degrees, so that a computed value of brightness cannot as yet be of any value for photometric purposes. As to the effects of variations in the values chosen for the constants, the altered results due to the use of the values 14,300 and 14,350 for the constant C_2 are shown by dashed lines. Either of these often used values would lead, with a given set of values for melting temperature, σ, and m, to computed values entirely outside the permissible range. It is true that for each of these values a melting point and a value of the mechanical equivalent could be chosen (the computed brightness varies directly with these) which would fit any experimental value found. The chief interest, however, in these computations lies in utilizing values for the constants derived as largely as possible from independent data.

Another characteristic of the black body at this temperature, which may be predicted from preliminary calculations, is that its color will certainly be very close to that of the carbon incandescent lamps which are now used for maintaining the value of the photometric unit. Thus the black-body color temperature of a " four-watt " carbon lamp is given, according to recent determinations,[14] as 2070 degrees, or only about thirty-five degrees from the platinum point, while the pentane lamp color is nearly 200 degrees lower (1885° K.).

II. DEVELOPMENT OF A SPECIAL DESIGN OF PLATINUM BLACK BODY, AND STUDY OF ITS PERFORMANCE.

(*a*) *Preliminary Work.*—The writer's interest in this problem was aroused in the course of an experimental investigation of the luminous emission of the black body, with particular reference to a determination of the mechanical equivalent of light. The melting point of platinum was one of the temperature points utilized, and certain characteristics of the emission, as well as the promise of experimental simplicity, made it appear desir-

able to investigate in more detail the suggestion of Waidner and Burgess.[15]

In this work the black body at the melting point of platinum was realized by following the suggestion of Mendenhall [16] to bend thin platinum foil into a wedge of narrow angle. It may

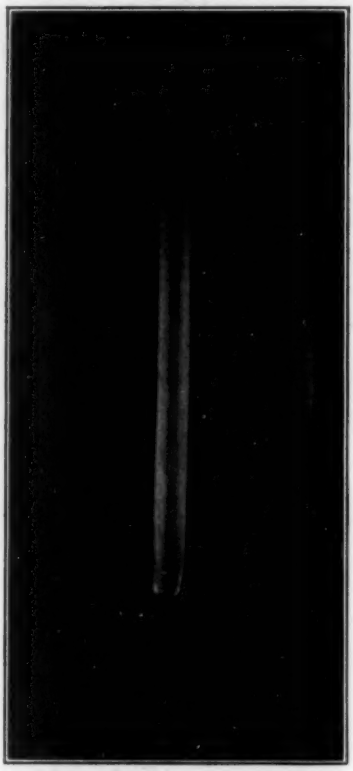
FIG. 9.

Glowing platinum cylinder viewed normal to slit, showing first image of slit.

be shown that the radiation emitted from a glowing wedge of this character becomes substantially identical with black body or complete radiation due to multiple reflection. The light from these wedges was passed through a small aperture and fell upon the screen of a Lummer-Brodhun photometer head. Subsequently some experiments were made with foil bent into the form of cylinders with a narrow opening on one side, the light from which

was observed in the same way. This work was, however, interrupted by the war, and the values obtained for the brightness of the platinum black body at the melting point were merely preliminary. The brightness values, as obtained from commercial

FIG. 10.



Similar view of cylinder with bruised inner surface.

platinum, were in the neighborhood of 58 candles per square centimetre.

Incomplete as this work was, it nevertheless confirmed the impression that the general scheme was very promising as a means of putting to a test the various suggestions to utilize platinum and the black body in connection with a standard of light. One additional merit of the black body at the melting point of platinum, which was clearly brought out by this preliminary work, in which

the illumination of the photometer field was favorable for accurate color comparisons, was that there is not only a close, but actually an almost perfect, color match between the black body at this temperature and the " four watt per candle " carbon incandescent

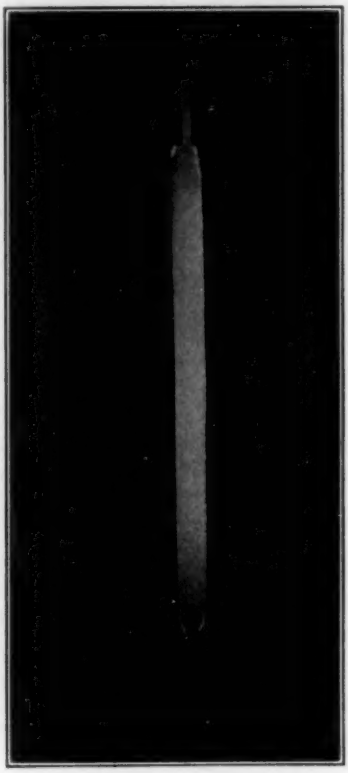
FIG. 11.

Glowing platinum cylinder with slit turned through angle of 30 degrees, showing second image of slit.

lamps which are now used to maintain the candle-power unit. It appears, in short, that all of the disadvantages which have been previously urged against platinum—such as possible contamination of its surface and its differences in color from other standards—are most satisfactorily absent in the proposed method of utilization by Waidner and Burgess.

(*b*) *Discussion of the Merits of Various Forms of Black Body.*—Several methods of achieving the black body at the melting point of platinum are possible. One is to imbed a hollow enclosure in a large mass of platinum, and observe the light from the enclosure at the instant the platinum melts. This scheme

FIG. 12.

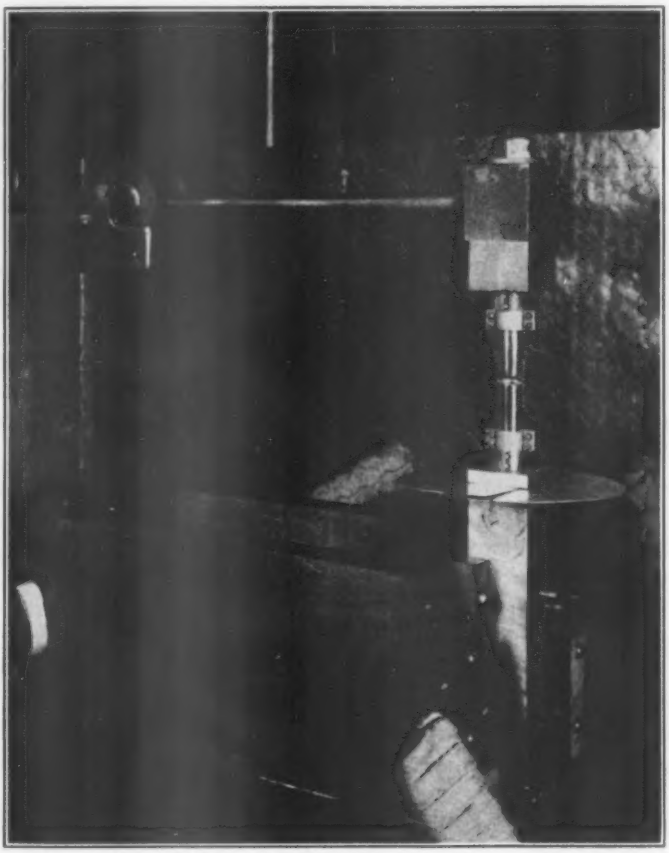


Glowing platinum cylinder with opening turned through angle of five degrees, showing practical black-body emission.

is better adapted to the converse process, namely, immersing a refractory hollow enclosure in a bath of molten metal and observing the *freezing* point. Certain objections may be cited against this method. One is that it is difficult to insure that the whole mass of metal (which is of comparatively low conductivity) will melt or freeze simultaneously at all parts of its volume, while

the mass and heat capacity of the refractory enclosure (the material of which would probably be a poor heat conductor) will always cause doubt as to whether it is accurately following the changing temperature of its surrounding bath. There also arises

FIG. 13.



First form of platinum cylinder holder.

the question of contamination of the metal from the material of its containing crucible and the black-body enclosure itself.

A second method is to insert small fragments or wires of platinum in a black-body furnace and observe the light from the latter at the instant the platinum melts, as shown by some con-

venient electrical or other indicator. An objection to this method is that it is difficult to insure that the metal fragment and the part of the furnace wall under observation are at exactly the same temperature, unless they are in contact. If they are in contact the question of contamination of the platinum by the furnace material arises. There is always, moreover, in this method the question of contamination by the products of evaporation from the furnace walls or heating elements.

In view of the objections to these methods it appeared to the writer essential to use some form of black body in which the whole mass of metal could be uniformly heated and in which the platinum was not in contact with any possibly contaminating material.

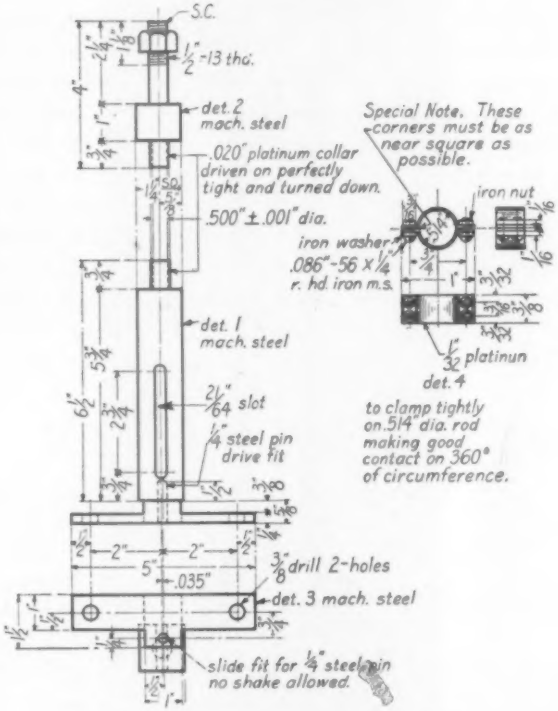
For this reason attention was directed at first to the platinum strip as proposed by Siemens, and adopted into a source of black-body radiation by Mendenhall. It was, however, found quite early in the work that the wedge used as a black body had a number of undesirable characteristics. The wedges are, for one thing, very much subject to deformation when soft; their temperature at the open end is greatly different from that at the vertex; and even with the utmost care it is not always possible to make the vertex of the wedge so sharp that a narrow dark line cannot be seen across the luminous area which is observed when looking straight into the wedge. Attention was consequently directed to other forms of black body which, while preserving the advantage of forming the black body entirely out of platinum, would, as well, be rigid, uniform in temperature distribution, and free from disturbing reflections.

This requirement was ultimately met by the use of *hollow cylinders* of thin sheet platinum. As the optical properties of such cylinders have not, apparently, been treated before, it will be necessary to outline these before proceeding with the mechanical and other details of their use in practice.

(*c*) *Optical and Radiating Properties of Hollow Reflecting Cylinders.*—The utilization of such a highly reflecting and therefore poorly emitting substance as platinum in the construction of a black body requires the production of such a geometrical form as will bring about a very large number of successive reflections of the emitted light. There will then be added to the light directly emitted enough reflected light to bring the apparent emission to that of a complete radiator. It is most convenient to investigate

this problem by studying the converse one, namely, the reflecting power of the platinum cylindrical enclosure. According to Kirchoff's law the emissive power is the complement of the reflecting power. Consequently it is sufficient if we determine under what conditions the reflecting power of the interior of a platinum cylinder becomes negligible, to have at once the

FIG. 14.


S.C.
1/2"-13 thd.
det. 2 mach. steel
.020" platinum collar driven on perfectly tight and turned down.
.500" ± .001" dia.
det. 1 mach. steel
21/64" slot
1/4" steel pin drive fit
2"
2"
5"
.035"
3/8" drill 2-holes
det. 3 mach. steel
slide fit for 1/4" steel pin no shake allowed.
Special Note. These corners must be as near square as possible.
iron nut
iron washer
.086"-56 x 1/4 r. hd. iron m.s.
1/32" platinun
det. 4
to clamp tightly on .514" dia. rod making good contact on 360° of circumference.

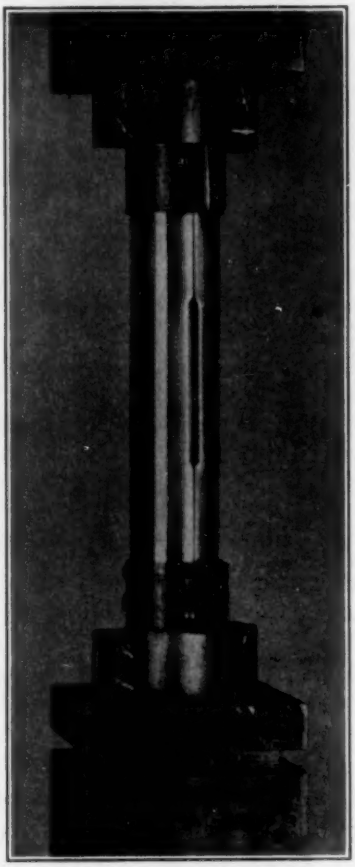
Details of platinum cylinder holder and clamps.

condition for complete emission when a cylinder is raised to a high temperature.

Before proceeding to the exact computations, the behavior of a hollow cylinder may be indicated in a qualitative way by referring to Fig. 2. In this figure the upper picture is a photograph of a glass cylinder which has been silvered on the inside and through a narrow opening at the front of which there shines the light from an extended luminous area. It will be seen that

directly opposite the narrow observation opening there is a bright reflection of the extended light area. To either side of this central reflection are bands of low reflecting power, followed further out by successive reflections of various widths and of intensities

FIG. 15.



Photograph of platinum cylinder with its clamps.

less than that of the central image. The lower picture in the figure shows the same cylinder turned through an angle of 30 degrees. The reflection which is now seen by looking through the opening is much less intense and narrower than that seen centrally. It is obvious that it is necessary only to make the

opening narrow enough and to turn it into the proper position, to receive a negligibly small and negligibly intense reflection from the interior of the cylinder.

It is now our problem to determine accurately the character and positions of these successive reflections and then to find how many reflections with our given material, platinum, are necessary to reduce the reflected light to negligible magnitude. To do this we proceed as follows:

Fig. 3 represents a section of a reflecting cylinder which is supposed to be standing opposite to an infinitely extended luminous plane perpendicular to the axis AA' and to be viewed from an infinite distance in the direction $A'A$. Let θ be the angle subtended by the arc between the axis and the point P where the line of sight cuts the cylinder. Let ϕ be the angle through which the slit—whose image is to be observed—is turned. Let ϕ' be the angle through which the slit has been turned referred to the point P, so that $\phi = \phi' + \theta$. We then have for ϕ, denoting by n the number of reflections the slit image has suffered, before incidence on the wall:

if

$n = 0$	$\phi' = \pi - 2\theta$	and $\phi =$	$\pi - \theta$
$n = 1$	$= 2\pi - 4\theta$		$= 2\pi - 3\theta$
$n = 2$	$= 3\pi - 6\theta$		$= 3\pi - 5\theta$
. .	. .		. .
$n = n$	$\phi' = (n+1)\pi - 2n\theta$	$\phi =$	$(n+1)\pi - (2n+1)\theta$

From this formula, by inserting successive values of ϕ, it is possible to obtain the position, through the angle θ, of the point P, which is the trace of the line of slight along which the nth reflection of the slit at position ϕ appears.

It will be apparent that for each value of n, the two angles ϕ and θ are connected by a linear relation. It is consequently possible to obtain the required information by simple graphical means. One method of doing this is shown in Fig. 4, where values of θ are given by the abscissæ and of ϕ by ordinates. Since we are only interested in the reflected images due to the slit moving from the zero position to the point at right angles to this, the first, fifth, ninth, etc., quadrants only have been subdivided into small enough angles (10 degrees) for accurate reading. This plot shows at once all the reflected images up to $n = 14$ due to the successive positions assumed by the slit as the cylinder is rotated.

At the bottom of the figure these reflections are all shown together, as they would be seen in turning the cylinder from zero to $\frac{\pi}{2}$, since the first, fifth, ninth, etc., quadrants are repetitions of each other. The $n = 0$ line, crossing diagonally from $\phi = 0$, $\theta = 0$ to $\phi = \frac{\pi}{2}$, $\theta = \frac{\pi}{2}$, and zigzagging upward through the diagram, is, of course, the slit itself, and its intersection with the various reflected images shows the points where, with a non-transparent cylinder, instead of the transparent one, here assumed, the slit reflection would be visible through the slit.

The treatment thus far covers the case of an infinitely narrow slit; practically we are interested in knowing how wide the slit may be made without reflections below the nth being visible. We must derive the formula for the width of the nth image. This may be derived by noting in Fig. 4 that when the slit moves through any angle the nth reflection moves through

$$\frac{\frac{\pi}{2}}{(n+1)\pi - \frac{\pi}{2}} = \frac{1}{2n+1}$$

of this angle. Hence the width of the reflected images will be $\frac{1}{2n+1}$ times the width of the slit.

The final steps in utilizing the data plotted in Fig. 4 and the formula just arrived at are shown in Fig. 5, where the positions of the reflections are shown (b) not in angular units but projected, as they would be seen looking in the direction of the axis AA' (Fig. 3) from an infinite distance, and (c) where a slit 10 degrees wide is developed, crossed by slit images derived from (b) but represented as of proper width. In this last figure the ordinates give the angles through which the cylinder has been turned when its appearance is represented by the horizontal element through that ordinate. For instance, when the cylinder is turned through 30 degrees the 10-degree opening will be crossed from top to bottom by a reflection of the slit one-fifth the width of the slit. When the slit is turned 5 degrees from the normal position it will be crossed by no reflections less than the tenth.

The question now arises, how many successive reflections are necessary from a platinum surface to reduce the reflected light to negligible amount? For this purpose we must know the

reflecting power of platinum. Values for this have been taken from the tables of Hagen and Rubens. Their values (which appear to be substantially correct up to the melting point [10]) are given in the following table:

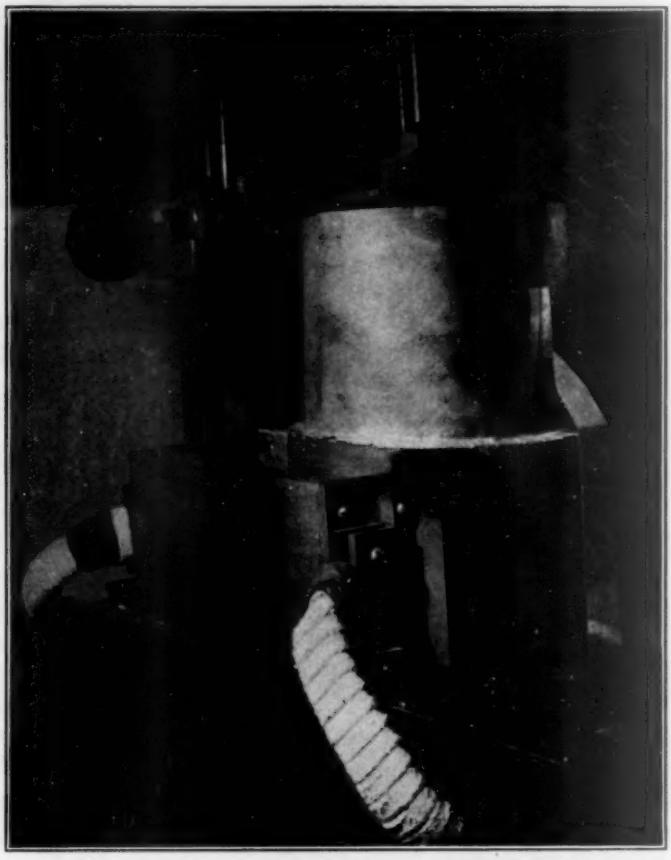
Wave-length.	Reflecting Power.
.45μ	.558
.50	.584
.55	.611
.60	.642
.65	.663
.70	.701

In order to find the reflected light after n reflections, we must raise these values to the nth power. Computations for wave-length, .6μ, are shown in Fig. 6 up to $n = 14$; and in Fig. 7 the fractions reflected by the tenth, twelfth, and fourteenth reflections are shown plotted through the visible spectrum. From these figures it is apparent that for glowing platinum near its melting point, whose effective wave-length will be .58μ, fourteen reflections will reduce the reflecting power to less than 1/5 of 1 per cent. Actually, however, we must bear in mind that the reflections corresponding to high values of n are exceedingly narrow and that any practical platinum surface will deviate enough from perfect specular character so that these narrow images will really be diffused and their intensity diminished in proportion to their size. This latter consideration makes it evident that it is actually quite sufficient to select a position for the slit in which no reflections of lower value than the eighth are present to insure that the reflected light shall be of intensity less than 1/5 of 1 per cent.

In accordance with Kirchhoff's law we may expect the bright reflections, which have just been considered, to be replaced, when the cylinder is raised to glowing temperature, by regions of low emission, and the positions of low reflection by regions of high emission. As a demonstration of these conclusions photographs were made of an electrically heated glowing platinum cylinder of the dimensions finally used in the work, some of which are reproduced in Figs. 8 to 12. Fig. 8 shows a side view of the cylinder on which various irregularities of the emission due to specks of dirt and surface imperfections are evident. This figure serves to illustrate the imperfections of the ordinary platinum surface as a definite radiating body for standard purposes. Fig. 9

shows a view looking directly into the platinum cylinder. It will be noted first of all that the opening is very much brighter than the exterior of the cylinder, illustrating the increased emission of a black body as compared with the surface of the metal.

FIG. 16.



Shield for protecting platinum from drafts.

Directly in the centre of the slit opening will be seen the strip of low emission corresponding to the bright reflected image in the silvered glass cylinder in Fig. 2. Fig. 10 shows the same view of a similar cylinder in which the surface of the platinum is not accurately specular, due to bruising, so that the dark slit image

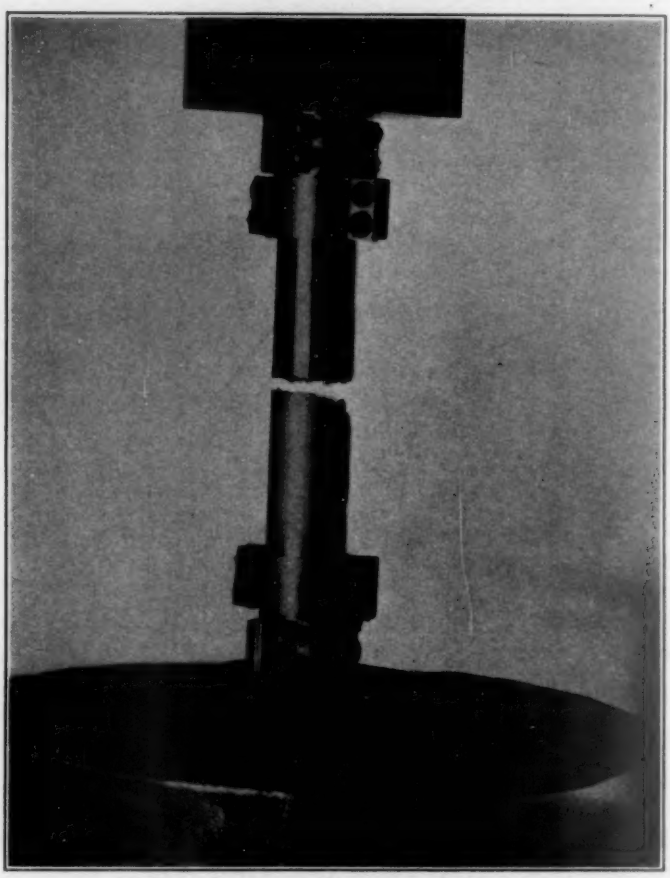
is less well defined. This is a condition, which, as will be described later, is to be avoided. Fig. 11 shows a cylinder turned through an angle of 30 degrees. In this case the image of the slit has been twice reflected: It is of very much less intensity and is only one-fifth the width of the opening. In Fig. 12 a cylinder is shown turned through an angle of 5 degrees, where, according to Fig. 5, the emission should be " black " to within a small fraction of 1 per cent. It will be seen from these figures that the method of realizing a black body by the use of a glowing cylinder is highly successful.

(*d*) *Construction and Manipulation of the Platinum Cylinder Black Body.*—It is, of course, obvious that the conditions assumed in the theoretical treatment just given must be closely approximated if the cylinder black body is to be satisfactory. This means that the temperature must be uniform around the complete circumference of the cylinder; that the surface must keep its plane highly reflecting character all the way up to the melting point; and that the cylinder must not suffer any deformation before melting. The first requirement was fulfilled by electrical heating of the platinum, using an intense alternating current; the auxiliary apparatus is shown in Fig. 13. The apparatus consists essentially of two steel rods twelve and one-half millimetres in diameter and nineteen millimetres long, mounted on heavy steel blocks arranged to stand one above the other along the same vertical axis. The steel rods are sheathed with heavy platinum cylinders as shown in the detail drawing (Fig. 14). The thin platinum cylinders which are to be melted are attached to these platinum-sheathed rods by four pairs of semi-circular clamps which are drawn up tight with screws, each pair of clamps being turned 90 degrees with respect to the adjacent pair; details are shown in Fig. 14, and in the large scale photograph, Fig. 15. This elaborate clamping system, while necessitating considerable length of dead end to the platinum cylinders, is very necessary to insure perfect contact and thereby uniformity of current density through the thin sheet platinum. The upper platinum cylinder holder is carried at the end of a long rod which is pivoted at its centre, where it dips into a mercury cup, and which carries at its far end a counterweight so adjusted that there is no tension on the platinum cylinder at the instant of melting. Current from the low-voltage side of a 220-volt, 10:1 transformer, is led to the two

ends of the platinum cylinder by heavy flexible leads as shown in Fig. 13.

In order to protect the platinum cylinder from drafts of air a thin metal cylindrical sheath, nearly closed at the bottom, is

FIG. 17.



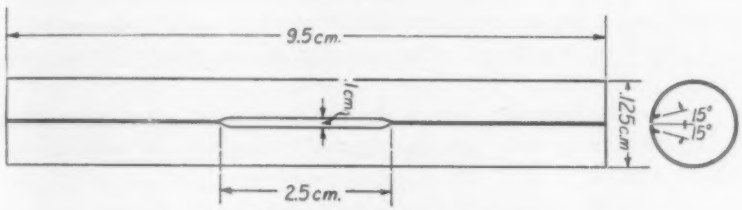
Melted cylinder, showing baffle plate at bottom.

placed around the central part of the system but not in contact with it (Fig. 16), and a baffle plate, as shown in Figs. 13 and 17, fitting into the groove shown in Fig. 15, closes the lower opening. To either side of the whole apparatus is placed a large shield, for which sheets of wired glass were used. By means of a rack

and pinion at the rear the whole platinum holder could be turned about a vertical axis through the front of the cylinder so that observation could be made at any desired angle.

The dimensions chosen for the platinum cylinders were adopted after considerable experimentation. The experiments were first made on commercial platinum with the idea of saving expense. It was ultimately found, however, that chemically pure platinum is so much softer than the commercial material that the proper dimensions could not be ascertained except by trial with the material to be actually used. The values of diameter and length of cylinder finally chosen were dictated largely by the method of observation used, which will be described in a later section.

FIG. 18.



Dimensioned sketch of platinum cylinder.

These values were 1.25 centimetres for the diameter and 5 centimetres for the clear length between the clamps. An additional length of 3.8 centimetres was provided for clamping. The thickness used in the preliminary work with commercial platinum was .05 millimetre. With chemically pure platinum, however, it was found that no assurance of freedom from crumpling and other kinds of deformation was obtained until the thickness was at least .15 millimetre. Fig. 19, a photograph of one of the thin cylinders tried at first, shows the kind of deformation which may be caused by the use of platinum of insufficient strength. In the final work thicknesses from .17 to .22 millimetre were used. Cylinders of this thickness are of very great rigidity, thus contrasting with the flimsy strips used by Siemens, and with the thin wedges used by Mendenhall. With these thicknesses it was found that the metal arm carrying the upper platinum holder as originally designed suffered expansion with the heat which was developed, subjecting the cylinders to strain before the melt, and it became necessary to provide additional current paths, which was done by adding

flexible copper leads, and radiating vanes. These latter were, however, later dispensed with in designing the final form of platinum holder, described in connection with the photo-electric observations.

The actual form taken by the cylinder is shown in Fig. 15. The platinum strips were cut of such width as to make completely closed cylinders of the prescribed diameter. They were then carefully annealed in a hot Bunsen flame. They were next rolled around a metal rod 1.25 centimetres in diameter. The centre 2½ centimetres of the closed cylinder thus attained, was then bent back over a shaping tool to give the final form shown by the section in Fig. 18. In doing this shaping it was necessary to turn back one edge at a time in order to permit the removal of the platinum from the shaping tool. This removal process had to be carried out with extreme care in order to prevent bruising of the soft platinum surface. The opening in the final slit was very closely 9 degrees.

After the cylinders were shaped they were carefully cleaned in hot nitric and hot hydrochloric acids, finishing off with distilled water, and were carefully dried in an oven.

(*e*) *Performance of Platinum Cylinders as Used.* In order to determine whether the platinum cylinders as thus mounted and heated conformed to the theoretical requirements, a number of observations and measurements were made upon them. The first of these observations consisted in observing the projected image of the platinum cylinder in a direction normal to the opening and observing whether, during the heating process previous to the melting, the sharp dark band shown in Fig. 9 remained unchanged. A cylinder was watched in this way right up to the melting point, and it was established that the specular quality of the platinum does persist to the last instant. This, of course, is strictly true only for a reasonably quick melt; that is, one in which the last 100 degrees of temperature are traversed in about a minute. It is probably true—although no systematic experiments were made to test the point—that if the platinum were allowed to stand for a long period close to its melting point the surface would become matt, under which condition the computations as to the nature of the reflection and emission would, of course, be invalid. The next experiments were undertaken to determine whether the temperature of the cylinder was uniform

throughout its circumference. This was tested first by observing the two projected edges of the cylinder as viewed side-on through a biprism. These observations were followed by a series of carefully made photographs of the cylinder taken with a cylindrical lens which smoothed out the local irregularities of brightness in the vertical direction. In Fig. 20 is shown a photograph of a cylinder taken from the side, of which the negative has been cut in two and turned over. Fig. 21 shows a similar photograph taken with the slit opening turned far to one side, the negative being again cut in two and turned over. A number of such photographs were taken and treated in this way and established very clearly that with the thickness of platinum used the temperature of the cylinder is uniform up to the edge of the slit. As a result of these experiments it was decided to work with the cylinders very close to the central image, that is, turning the 9-degree slit through an angle of only 5 degrees from the central position. On referring to the geometrical study as embodied in Figs. 4 and 5, it will be seen that the approximation of black-body conditions is here practically perfect, that is, the error will probably be less than .1 of 1 per cent.

(*f*) *Preparation and Working of Chemically Pure Platinum.*—The chemically pure platinum used in the significant determinations was obtained from two sources: The first lot was purchased, in the form of platinum strip rolled to the right thickness, from Baker and Company, of Newark. A sample of this was submitted to the Bureau of Standards, to be tested for purity in comparison with spectroscopically pure platinum and the following report was rendered:

"The thermo-electric comparison was made by joining a sample to the standard and inserting the junction into a clean furnace at 1200° C. The cold junctions of this couple were kept at 0° C.

"The sample A gave 148 microvolts and was thermo-electrically positive to the standard. This E.M.F. is equivalent to an impurity of 0.07 per cent. rhodium, or of 0.04 per cent. iridium or 0.05 per cent. calcium."

The second and third lots of platinum were purified by Dr. J. E. Harris, of this laboratory, according to the following method:

The bulk of the impurities are removed by the method described by Mylins and Mazzucchelli (*Zeit. fur Analyt. Chem.*,

89, 1), which consists of adding bromine to a slightly alkaline solution of sodium chloroplatinate. This throws out the iridium, rhodium and palladium in combination as dioxides. After filtering, a solution is obtained containing platinum 99.9 per cent. pure. This is purified further by two recrystallizations of the sodium chloroplatinate from a slightly alkaline solution. The second crop of crystals is dissolved in water, acidified, evaporated to dryness, and thoroughly dehydrated to remove the silica. The sodium chloroplatinate is dissolved in water and the platinum precipitated with ammonium chloride as ammonium chloroplatinate. The precipitate is filtered, thoroughly washed and ignited to the sponge. After repeated washings with hydrochloric acid and distilled water, the sponge is ready for use.

Two lots of platinum were prepared in this way, the first, 700 grams, used in part of the visual observations, the second, 1200 grams, used in the photo-electric observations. The platinum, in the form of sponge, was sent to Baker and Company for melting and rolling into sheets. Special precautions were taken in the melting to prevent contamination; the lime crucibles used were specially selected, and the surface of the ingot was planed off before the rolling.

Samples of these two lots of platinum, cut from the rolled sheets, were also submitted to the Bureau of Standards for test. The first sample "gave +87 microvolts against the standard, which E.M.F. is equivalent to 0.04 per cent. rhodium, or 0.029 per cent. iridium, or 0.03 per cent. calcium." The report on the second sample stated "the test platinum was found to be 61 microvolts positive to the Bureau of Standards' purest platinum. . . . This E.M.F. indicates the presence of about 0.02 per cent. calcium, if calcium is the sole impurity."

With regard to the possible effect of such small amounts of impurity on the melting point, the Bureau of Standards' report states:

"There are not sufficient data available to afford means for estimating the effect of such amounts of impurities on the melting point of the platinum. We do not know of any experimental work on the melting point of platinum, in which sufficient precision was obtained to give measurements of small differences in melting point of different samples."

"We have made such comparisons with samples of gold and palladium and have found that metals of approximately the degree of purity of your platinum differ in melting point by a few tenths of a degree. For example: Four samples of palladium gave melting points over a range of 0.29° C. and E.M.F. against a standard

FIG. 19.

Thin cylinder after melt.

over a range of 93 microvolts. A fifth sample gave 300 microvolts against a standard and melted 0.31° below the standard. A sixth gave 2500 microvolts and melted 1.95° below the standard. The seventh gave 3800 microvolts and melted 1.20° high. All the E.M.F.'s are plus to the purest sample and are obtained at the melting point of palladium."

It appears safe to conclude from these tests that the deviation

of the melting point of the platinum used from that of spectroscopically pure platinum is not over two or three-tenths of a

FIG. 20.

Side view of cylinder; negative cut in two and one half reversed in printing.

degree centigrade, which will affect the brightness by not more than $^1/_5$ per cent.

In the rolling of the platinum the chief problems are the attainment of satisfactory uniformity of thickness and a plane, highly polished surface. The actual thicknesses of the various

FIG. 21.

View of cylinder with slit to one side; negative cut in two and reversed in printing.

strips used in the study varied from one to another by as much as 5 per cent., but the variation in any one strip was much less, and the variation in the sections cut off to make individual cylinders was not over 1 per cent. Any accidental flaws, such as blis-

ters or cracks, were of course avoided in cutting off the sections for shaping into cylinders.

The production of a plane and highly polished surface is a matter of the preparation of the silver rollers used to bring the platinum to proper thickness, no polishing process being used on the platinum itself, in order to avoid contamination by polishing material. The most serious defect likely to occur is the production of minute ridges or hillocks of sufficient size to blur the reflected slit images. The test for planeness of surface is a simple one; the dark central shadow in the glowing cylinder, as observed in its enlarged projected image, must be sufficiently sharply defined as to place it beyond question that the dark portion is not encroaching on the region selected for observation. Fig. 9 shows a case where this requirement is well met, while Fig. 10 shows a case where (owing here to bruising of the surface of the platinum) the dark central image is less well defined. No simple criterion for polish exists, but as long as the polish appears high it is to be considered satisfactory, since a uniform dulness of the surface merely means a step toward a uniform matt condition, which, because of the small aperture in the cylinder, would still leave the structure a very good black body.

There is always considerable unavoidable reduction in the available metal incident to the fabrication into sheets, owing to planing off the outer layer of the ingot and the trimming of sides and ends. In addition the development of blisters on rolling and annealing is apt to take heavy toll. Of the first lot of platinum sponge (700 grams) only about one-third was ultimately available; the second lot (1200 grams) was more satisfactory in this respect, as the tendency to blister developed only toward one end of one of the two sheets delivered (500 grams) and necessitated discarding only the equivalent of two cylinders.

(To be concluded.)

Ferric Oxychloride.—R. B. SMITH and P. M. GIESY (*J. Am. Pharm. Asso.*, 1923, **12**, 855–856) have demonstrated the non-existence of ferric oxychloride, by titration of ferric chloride with sodium hydroxide, using the oxygen electrode. The resulting curve was typical of that obtained on neutralization of a strong acid by a strong base; it was entirely free from breaks which would have been present if a basic or intermediate salt had been formed. J. S. H.

SOFT X-RAYS FROM TUNGSTEN.*

BY

C. B. BAZZONI and C. T. CHU.

PART I. GENERAL THEORY.

CERTAIN facts concerning the structure of atoms are now generally accepted. Atoms are known to be aggregations of positive and negative electricity in which the positive electricity is concentrated into an extremely minute central nucleus with the negative electricity spatially distributed in discrete equal portions —electrons—around it. The net positive charge on the nucleus, called the atomic number, and therefore the total number of electrons in the normal atom, is known for each of the chemical elements. It is admitted that these electrons are arranged in shells or layers, although there is no accurate knowledge of the dynamics of such systems excepting for the hydrogen atom. The differences in properties which distinguish the elements are probably determined by the mode of arrangement of the electrons in these shells, but it is not completely known how the electrons are distributed in the shells or what the motions of the systems may be. Of the theories which have been advanced to cover these points, that of Bohr [1] has the greatest strength at the present time. This theory gives a connected picture of the mode of building up of the atoms from hydrogen to uranium by the successive additions of electrons one by one affording a plausible explanation of the changes in the physical and chemical properties even through the rare earth and other anomalous groups and predicting to a large extent the constitution of the X-ray spectra. Although at present almost entirely without any mathematical basis, the theory is in many particulars so in accord with the X-ray measurements of Siegbahn and his associates and others [2] that the probability of its truth increases day by day.

* Communicated by Professor Bazzoni. Contribution from the Randal Morgan Laboratory, University of Pennsylvania.

[1] *Zs. f. Phys.*, **9**, 1, 1922.

[2] Siegbahn u. Jönsson, *Phys. Zs.*, **20**, 251, 1919; Siegbahn, *Phys. Zs.*, **20**, 533, 1919; Siegbahn u. Dolejsek, *Zs. f. Phys.*, **10**, 159, 1922; Coster, *Phil. Mag.*, **43**, 1070, 1922, and **44**, 546, 1922; Bohr and Coster, *Zs. f. Phys.*, **12**, 342, 1923; Hjalmar, *Zs. f. Phys.*, **15**, 65, 1923.

The details of this theory are well covered in the references given above. We will here very briefly outline certain features of the theory which have to do with the production of X-rays. X-radiation is developed when an electron readjustment takes place among the shells of an atom subsequent to the forcible ejection of an electron from an inner shell by any agency as, for instance, by impact of a free electron. The energy radiated is the difference between the energy of the atom prior to the readjustment and its energy subsequent to the readjustment. This energy diffrence, W_R, is related to the frequency, ν, of the radiation by the equation $W_R = h\nu$ where h is Planck's constant. This relation is the same as the one fundamental in the application of the Bohr theory to optical spectra.

If a continuous spectrum of X-radiation is allowed to pass through a screen of atoms of a particular construction, the atomic systems will absorb from the radiation those frequencies the quanta of which, as given by the $h\nu$ products, are exactly sufficient to lift electrons from the different shells out of the atoms or into exterior shells in which gaps may exist. Measurements of the absorption spectrum thus produced will establish the number and relative energy values of the successive shells or layers in the atom. Working on the heavy atoms, uranium and thorium, six shells have been discovered, each shell consisting of a group of related shells. These six shell groups are denominated the *K*, *L*, *M*, *N*, *O* and *P* groups, beginning with the innermost. The *K* group has one member only, the *L* group three, the *M* group five, the *N* group seven, the *O* group five and the *P* group three. According to the Bohr theory the electrons in any one of these shells are moving in orbits more or less elliptical and spatially arranged, that is, not generally coplanar. Furthermore, due to great variations in eccentricity, the orbits of the different shells are interpenetrating, electrons in exterior shells coming very close to the nucleus at perihelion of the highly elliptical orbits. Consequently the force acting on an electron in an elliptical orbit undergoes enormous variations during a revolution, the inverse square relation being approximated only in the exterior parts of the orbit. We have to deal therefore with "effective nuclear charges," and with "effective orbit numbers," which may differ considerably from the corresponding quantities ordinarily to be expected. It thus happens that the net binding

force on electrons in exterior shells may in certain cases be greater than that acting on electrons in interior shells. This is a fact of great importance in the theory. It goes without saying that the dynamics of such systems are at present entirely without solution or adequate mathematical representation.

The energies of the levels in the atoms are given in quanta with reference to the atomic centre—the K level is a one-quantum level, the L level a two-quantum level, the M a three-quantum level, and so on. The total energy in any particular orbit is dis-

FIG. 1.

Shell.	K	L	M	N	O	P
Orbits Q_K ..... Total quanta Q Azimuthal quanta K	1_1	$a2_1$, $a2_2$ $b2_1$	$a3_1$, $a3_2$, $b3_1$, $b3_2$, $b3_3$	$a4_1$, $a4_2$, $a4_3$, $a4_4$, $b4_1$, $b4_2$, $b4_3$	$a5_1$, $a5_2$, $b5_1$, $b5_2$, $b5_3$	$a6_1$, $a6_2$, $b6_1$
Symbol of Corresponding Absorption Limit	K	L_3 L_1 L_2	M_4 M_2 M_1 M_5 M_3	N_6 N_5 N_2 N_1 N_7 N_4 N_3	O_4 O_3 O_1 O_5 O_2	P_2 P_1 P_3
ν/R for W ..... [Introduced as an example]	5113.8	850.1 751.6 890.6	188.9 167.4 133.2 207.6 137.8	35.6 30.6 2.5 2.5 43.6 18.7 17.8	2.9 2.9 (o) 5.2 (o)	

tributed by quanta between the radial motion of the electron and its azimuthal motion. This distribution is specified by sub-figures representing the azimuthal quanta on the figure representing the total quanta of the orbit. For instance, 3_2 represents a three-quantum orbit with two quanta of azimuthal energy, that is, an ellipse of moderate eccentricity, while 3_3 represents an orbit with its whole energy azimuthal, that is to say, a circular orbit. There are evidently two types of two-quantum orbits, three of three-quantum, four of four-quantum, and so on. The matter is further complicated by the existence of two sub-types of certain of these orbits; types specified by a and b coefficients, for example, $a3_2$ and $b3_2$. These orbits have perhaps the same shape but different effective energies. The complete system of X-ray orbits is represented in Fig. 1.

The notation used is that of Coster [3] and of Hjalmar.[4] The ν/R values for tungsten are from Bohr and Coster.[5] For purposes of calculation the energies of the orbits are represented either by

[3] Coster, *Phil. Mag.*, **43**, 1070, 1922.
[4] Hjalmar, *Zs. f. Phys.*, **15**, 65, 1923.
[5] Bohr and Coster, *Zs. f. Phys.*, **12**, 342, 1923.

ν/R, where $\nu = 1/\lambda$ and R is Rydberg's constant, 109,737, or by the square root of ν/R. The simple Bohr theory gives an expression

$$E_r = \frac{2\pi^2 m_e e^4 N^2}{h^2} \times \frac{1}{n^2}$$

for the total energy of the atom in a state specified by the integer n, for instance, with its electron in the nth possible orbit. When

$$R = \frac{2\pi^2 m_e e^4}{h^3}$$

this energy is seen to be expressible by

$$E_r = RN^2 h \times \frac{1}{n^2}$$

where N is, as usual, the atomic number. This energy content being equatable to $h\nu$, we see that

$$\frac{\nu}{R} = \frac{1}{n^2} \times N^2$$

and ν/R is therefore a quantity proportional to the energy of the state. Since for a fixed value of n the square root of ν/R is proportional to N (Moseley's law) it is convenient to use these two quantities, $\sqrt{\frac{\nu}{R}}$ and N, as coördinates in plots representing the properties of successive elements. The lines thus obtained may be called Moseley's lines.

If now an atom is stimulated to emit X-rays by electronic impact the energy liberated can be calculated, since it is developed by transference of an electron from an exterior orbit to the interior one from which an electron was ejected by the impact, by subtracting the energy of the final configuration from that of the initial configuration. We thus see that each emission line can be represented as the difference of two absorption levels. It is evident from Fig. 1 that there are fifteen possible transfers from the M shell into the L shell and twenty-one from the N shell to the L and so on giving a total of sixty possible L emission lines. This number of possibilities is materially reduced by the application of a combination principle[6] consisting of two parts: (1) Only such electron transfers can take place as either leave the

[6] The first clause of this principle was suggested by Rubinowicz (*Phys. Zeit.*, 19, 441 and 465, 1918) and modified by Bohr. The second was suggested by Wentzel (*Zeit. f. Phys.*, 6, 84, 1921). The form of expression used above is that of Hjalmar (*Zeit. f. Phys.*, 15, 65, 1923).

azimuthal quantum number, k, unchanged or else change it by one unit only; (2) all electron transfers must be from an a type orbit to a b type orbit or *vice versa*. The lines predicted by the theory through the application of these rules have nearly all been found experimentally. These rules when applied to N to L transfers reduce the possibilities from twenty-one to seven, of which six have been found (Coster); applied to M to N transfers the number left to be expected is thirteen, of which ten have been found (Hjalmar). It is evident that the relative amounts of energy necessary to excite particular lines give a measure of the relative tightness of binding of the electrons in the orbits concerned and that the disappearance of a particular line from the spectrum on passing from an element of a certain atomic number to the one next lower gives an indication of the disappearance of an orbit of a particular type from the structure. Thus we are enabled

FIG. 2.

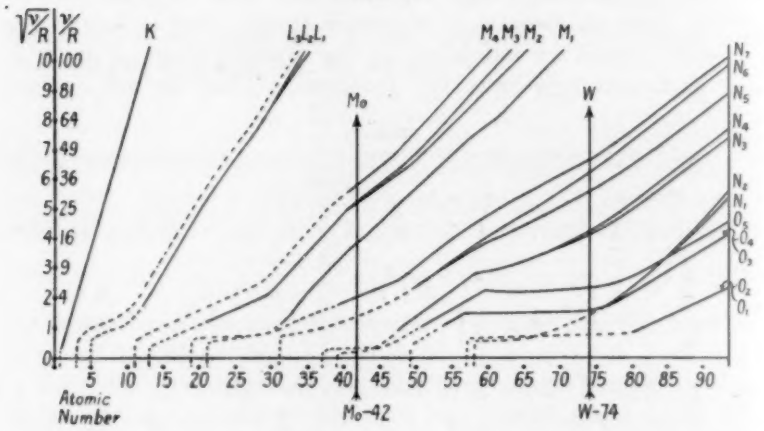
Atomic Number.	Element.	Orbits.				
		K	*L*	*M*	*N*	*O*
		1_1	2_1 2_2	3_1 3_2 3_3	4_1 4_2 4_3 4_4	5_1 5_2 5_3
36	Kr	2	4 4	6 6 6	4 4	
37	Rb	2	4 4	6 6 6	4 4	1
38	Sn	2	4 4	6 6 6	4 4	2
	Yt to Pd—transition stage of elements—electrons filling up into inner orbits of the 4 group.					
47	Ag	2	4 4	6 6 6	6 6 6	1
54	Xe	2	4 4	6 6 6	6 6 6	4 4
79	Au	2	4 4	6 6 6	8 8 8 8	6 6 6

gradually to piece together the evidence on which to base assured statements relative to the internal structure of the atoms.

When all the evidence has been considered it is possible to specify the construction of certain atoms with some assurance.

It becomes apparent, however, that, as already intimated, a more stable configuration may sometimes be reached in the process of building up by filling into orbits of higher quantum number while ones of lower number are still incomplete. For instance (Fig. 2), element 36 has four electrons in each of two orbits of the four-quantum group. Element 37 adds an extra electron in the 5_1 group, leaving the 4_3 and 4_4 groups empty. These vacant interior orbits are filled up subsequently in moving up the list of elements, representing a transition stage during which it is difficult to ascertain the precise structural steps. Element 47 in which the

FIG. 3.



transition is completed has, it will be observed, six electrons in each of three orbits of the four-quantum group, but all the four-quantum group orbits are not filled until element 79 is reached, where we have also already eighteen electrons in the five-quantum section. These conditions, which arise when, due in part to the interpenetration of the orbits, the energy content of successive orbits does not change in a direct and proportional way with the successive addition of electrons, are reflected in diagrams representing the energy values of the different levels, or orbits, for the various elements. Fig. 3 is such a chart.

Here it will be noted, as an example, that for elements below atomic number 84 the energy contents of the N_1 and N_2 orbits are less than that of the O_5 level. It is to be expected, therefore, that, in passing from element to element, electrons will occupy

first the O_5 level, leaving the higher N levels empty. How these and numerous similar considerations explain in a striking manner certain physical and chemical properties of the elements has been well demonstrated by Bohr.[7] This figure shows most clearly where in descending the series of elements from more complex to less complex atoms the outer orbits successively disappear. For example, the O_5 level, which Fig. 1 shows to be the 5_1 orbit, disappears below element 37.

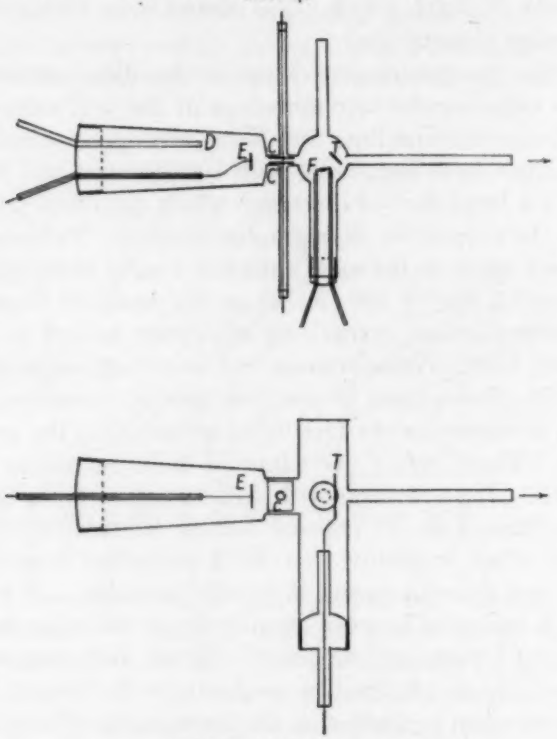
It is clear that quantitative checks on this theory must be based largely on experimental determinations of the ν/R values for the various X-ray emission lines and X-ray absorption edges. These determinations have been made with completeness and some precision over a large part of the range which can, with present-day apparatus, be covered by photographic methods. References have already been given to the most authentic results along these lines. The curves of Fig. 3 are plotted on the basis of these experimental determinations, comprising absorption as well as emission data drawn from diverse sources and involving, especially when dealing with photographs of emission spectra, somewhat indirect reasoning to determine the final orbit concerned in the production of a line. These curves are admitted to be inaccurate in their lower parts. Here, dealing with soft radiation from heavy elements, the curves are of unusual interest because they definitely cross each other, indicating that for a particular atomic number either of two exterior orbits is equally probable. A change in structure is indicated between atoms lying to the right and to the left of one of these critical points. Direct information in this region can only be obtained by studies of soft X-rays, but very soft X-rays cannot be studied on the photographic plate and information on the P and O levels must therefore be sought with devices other than the photospectrograph. An obvious mode of investigating these soft radiations is through an examination of the photo-electric emission stimulated by them from an electrode exposed to the radiation. Part 2 of this paper describes certain measurements of soft X-rays from heavy elements made by this method. These measurements will be seen to fit well into the curves of Fig. 3.

[7] *Zs. f. Phys.*, **9**, 1, 1922.

PART 2. EXPERIMENTAL PROCEDURE.

Soft X-rays from solids have been investigated by Kurth,[8] Hughes,[9] Mohler and Foote,[10] Holtzmark [11] and Richardson and Bazzoni.[12] The elements studied have been carbon, molybdenum, copper, iron, nickel and aluminum. The experiments reported on

FIG. 4.



Device of blown quartz.

here are an extension of the work of Richardson and Bazzoni carried through with the same apparatus described by them in the *Philosophical Magazine* (**42**, 1015, 1921). This is a device of blown quartz, sketched in Fig. 4, constructed by the Silica Syndi-

[8] *Phys. Rev.*, **18**, 461, 1921.
[9] *Phil. Mag.*, **43**, 145, 1922.
[10] Bureau of Standards Sci. Paper No. 425.
[11] *Phys. Zeit.*, **23**, 252, 1922; *Phys. Zeit.*, **24**, 225, 1923.
[12] *Phil. Mag.*, **42**, 1015, 1921.

cate, Newcastle-on-Tyne. The electron source is a tungsten filament, *F*. The target under investigation is supported at *T*, in front of the throat of the plate condenser *CC'*. This condenser is of a single pair of plates and, being properly charged, prevents the passage of electrons or of stray plus ions into the chamber *D*, which contains a photo-electrically sensitive disc (copper), *E*, in connection with a quadrant electrometer. The distance, target to disc, is about three centimetres; the distance between the condenser plates about one millimetre. This apparatus is not easy to use. The simple condenser for controlling leakage into the measuring chamber will only function in an extremely high vacuum and with a critical and somewhat variable adjustment of the various potentials, especially that of the condenser with reference to the filament. With sufficient experience the arrangement can, however, be made to work in a satisfying manner, and good runs can readily be distinguished from those into which some disturbance has entered.

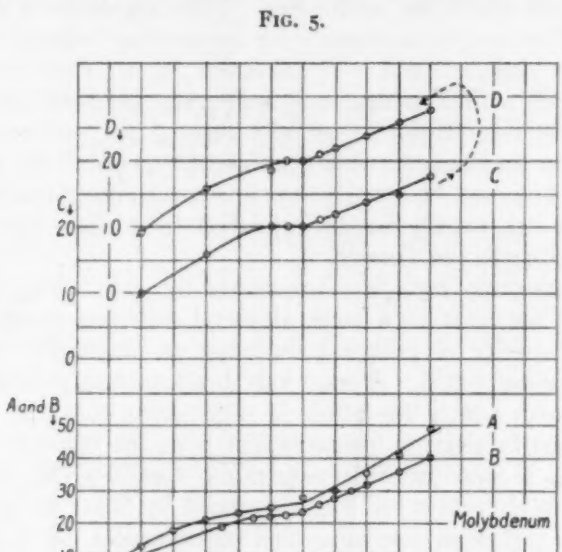
The apparatus was direct connected by wide tubing through two liquid air traps to a large all-metal diffusion pump backed by high capacity oil-pumps comprising an unusually fast and efficient vacuum outfit. A 2000-volt direct current generator was available with which the target or other parts could be brought to a red heat by electron bombardment from the filament. In the cleaning up process the entire apparatus, excepting the seals, was held at a high yellow-red heat produced by blast lamps placed beneath it for about one hour, and subsequently the target was kept at a red heat by bombardment for a similar length of time. This procedure, carried out in the presence of liquid air, produced that unusual degree of cleanness which made it possible to get the results shown.

In the experiments reported on here, the electrodes were cemented into the ends of the quartz tubes with a special sealing wax, but the apparatus has now been reconstructed with tungsten-pyrex seals fuzed to the quartz by Cooper-Hewitt joints. The wax joints were all, by design, distant from the experimental chamber and were water cooled, but naturally gave much trouble, being probably the source in one way or another of most of the disturbances encountered in the measurements.

The driving potential, filament to target, was obtained from a potential divider placed across a 660-volt storage battery, and

was measured with a first-grade Weston voltmeter checked against a calibrated Weston Laboratory Standard voltmeter. The electrometer was a Dolezalek with a sensitivity of about 800 millimetres a volt. The observations made in this work merely recorded the photo-electric emission from the disc as a function of the driving potential applied, filament to target. The upward breaks in the curves show that radiation is emitted from something, presumably the target, under bombardment of electrons

FIG. 5.



with a maximum energy registered by the voltmeter. In order to get the electron emission necessary to heat the target to redness in the clean-up, a long filament was necessary, but by using two spirals of heavy wire in parallel the potential drop in the filament could be kept down to about two volts. The apparatus is provided with an extra device to determine the velocities of the emitted photo-electrons by bending them into circles in a magnetic field, thus measuring more directly the frequency of the incident radiation, but this arrangement was not used in the work described below.

In order to make certain that the apparatus was functioning properly by checking it against previously established results, a molybdenum target was first introduced, and after the usual stringent cleaning operations the curves shown in Fig. 5 were obtained. In these curves a saturation of the radiation from gas, plus that possibly developed from the target at lower voltages, is reached at about 300 volts, and the setting in of a new effect is easily detected at 350 volts (uncorrected). Here, as elsewhere, the radiation curve is typically a straight line indicating a proportionality between the radiation and the excess of voltage above the critical threshold. Curve *D*, taken with falling voltage after curve *C* had been taken with rising voltage, is practically identical with *C*, and is shown as an indication of the reproducibility of the observations.

In these runs a single filament was used with a total drop along it of nearly seven volts and, through oversight, the plus end was connected with the voltmeter. This, by rendering correction more difficult, somewhat affected the precision of the results and, therefore, no attempt was made to correct the readings to better than one-half volt. After making an end correction to allow for the drop on the cold part of the filament and a correction for initial velocities, which was about three-tenths of a volt, slightly more than six volts must be added to the voltmeter readings to get the maximum energy of the bombarding electrons on the face of the target. It is thus seen that radiation is developed from molybdenum under 356-volt impacts. This result is a good check on the one obtained by Richardson and Bazzoni in 1921 which was also 356 volts.

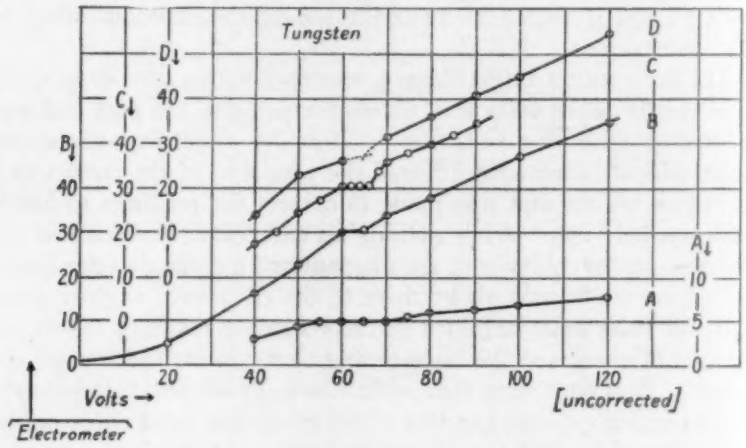
The radiation corresponding to this voltage calculated from the $eV = h\nu$ relation is 34.7Å [$\sqrt{\nu/R} = 5.14$]. This radiation may be identified with the M_3 line of molybdenum, as was pointed out in the earlier paper. The value fits with sufficient accuracy into the curves of Fig. 3 above the atomic number of molybdenum, 42.

The initial, slowly rising part of the curves, indicates the presence of a small amount of gas due to a minute air leak. Since the pumps were operating continuously, the air was removed as fast as it came in, and the McLeod gauge showed a zero reading (less than 10^{-5} mm.), but the presence of oxygen was indicated by a deposit of molybdenum blue which was found on the target at the end of the run. Since critical X-ray values for air were discov-

ered by Mohler and Foote at 345 volts and at 368 volts, uncertainty might be felt as to the source of the radiation here detected. However, in the work previously done on molybdenum by Richardson and Bazzoni there was no leak, the vacuum as measured with a three-electrode device being of the order of 10^{-8} mm., and the target was clean and silvery at the end of the run—yet the same critical point was obtained. We are therefore justified in ascribing this point to molybdenum.

The apparatus was next dismounted and thoroughly cleaned in all parts. A target of sheet tungsten was introduced, the

FIG. 6.

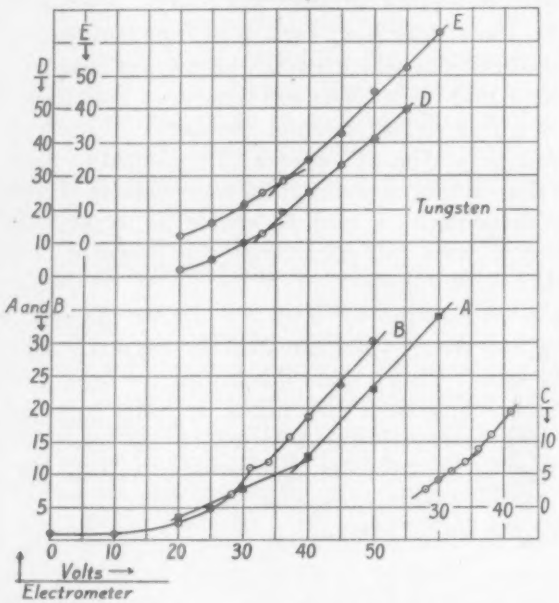


clean-up carried through, and curves obtained of which those in Fig. 6 and Fig. 7 are samples.

Here again (Fig. 6) we have evidence of a certain amount of gas radiation or of radiation from the metal at lower critical potentials, the effect of which is much more serious than with molybdenum since the critical point now sought lies well below the potential at which this preliminary current shows any tendency to flat off even under very moderate bombardments. Curve *A* (Fig. 6) shows a case where the bombarding current is so reduced that a virtual saturation is obtained near 50 volts. The radiation is, however, also reduced to such an extent that the threshold is apparently about five volts higher than on the curves representing heavier currents. Curves like *A* and *C*, nevertheless, justify one in stating that a radiation from tungsten sets in under impacts of

65 to 66 volts (uncorrected). Here again the single filament was used with plus end on the voltmeter so that six volts must be added as a correction. We thus obtain 71 to 72 volts as the corrected critical value. The only other value published for tungsten in this region is that of Mohler and Foote, who obtained 60 volts from a nickel target which had become sputtered with tungsten through use. The values for the O_5 level for tungsten recently determined by Hjalmar by deductions from data photo-

FIG. 7.



graphically obtained, give 5.2 for ν/R (Fig. 3). This ν/R corresponds to 70.45 volts, to which our critical potential is as close as the character of our corrections would lead us to expect to get it.

The magnitude of the radiation effect was apparently dependent on the position and inclination of the target—very probably merely on the projected cross area visible from the photo-electric disc. Due to softening of the target stem under the clean-up heating the target might turn or drop slightly under its own weight, thus altering its position in an undetermined way. However that may be, curves like those of Fig. 6 could be obtained only when the intensity of the radiation was so reduced that the

effects arising from the critical points lower than 70 volts were not great enough to deflect the electrometer through a large angle. This condition was apparently satisfied when the target was slightly displaced with reference to the line through the condenser to the photo-electric disc. When the target was more accurately centred curves like those of Fig. 7 were obtained. In this case, the critical points being lower, the disturbances due to radiation from residual gas are still more serious, the radiation breaks being evidenced only by alterations in slope which are not too certainly to be differentiated from ordinary gas effects. Curves like *A* and *C* (Fig. 7) show, however, such a definite change of slope at points the positions of which are not highly sensitive to variations in gas content that the authors are convinced that they constitute evidence of a true radiation from the metal. Curve *B* is introduced as one of a type of curve which probably means nothing more than that an erratic observation was made at 31 volts. *A*, *E*, and, more particularly, *C* and *D*, enable us to establish 34, 33, 38.6(?) and 36 volts (all uncorrected) as potentials for developing radiation from tungsten.

In the work covered by Fig. 7 a double filament was used with a drop in it of 2.5 volts and with the negative end connected to the voltmeter. Under these conditions we have assumed the end correction to balance the initial velocity correction. The voltmeter was, however, found to read 6/10 volt low over this range, so that we have for the final corrected critical values:

33.6, 34.6, 39.2 and 36.6 volts.

It is not wise to claim an accuracy better than one volt for these determinations. They lie in a region not previously investigated and are unchecked by other observers. Hjalmar's published values for the N_1, N_2 and N_3 levels for tungsten, which were obtained by calculation through the application of certain combination principles, together with Bohr and Coster's somewhat older values for the $O_{3\text{-}4}$ and O_5 levels, are as follows:

N_1	$\nu/R =$ 2.5	corresponding to 33.9 volts	.....	$\sqrt{\nu/R} = 1.58$
N_2	$\nu/R =$ 2.7	corresponding to 36.7 volts	.....	$\sqrt{\nu/R} = 1.64$
$O_{3\text{-}4}$	$\nu/R =$ 2.9	corresponding to 39.3 volts	.....	$\sqrt{\nu/R} = 1.70$
O_5	$\nu/R =$ 5.2	corresponding to 70.45 volts	.....	$\sqrt{\nu/R} = 2.28$
N_3	$\nu/R =$ 17.6	corresponding to 238.6 volts	.....	$\sqrt{\nu/R} = 4.20$

These values differ from the ones given in Fig. 1 in that Hjalmar's more recent determinations differentiate the N_1 and N_2 levels.

Here we have, as previously pointed out, the five-quantum

levels, O_5 and $O_{3\text{-}4}$, with greater negative energies than the four-quantum levels, N_1 and N_2. This condition is shown graphically in Fig. 3 above the atomic number of tungsten, 74. The O_5 level ($\nu/R = 5.2$—corresponding to 70.45 volts) has been experimentally located, it will be recalled, by the curves of Fig. 6.

If we assume an accuracy of one volt for our experimental values we can identify the 33.6 and 34.6 points, taken as one, with the N_1 level—the 36.6 point with the N_2 level and the 39.2 volt point with the $O_{3\text{-}4}$ level. We, however, do not claim this differentiation at the present time on account of the undeniable presence of a certain amount of gas radiation. We merely claim that these observations establish the presence of tungsten X-radiation from the O and N levels between 34 and 39 volts and that the radiation, taken as a group, starts within a half volt of 34 volts. It must not be forgotten that the values given by Fig. 3 for the energies of the outer orbits are admittedly uncertain and liable to alteration.

The modified apparatus with the leads fuzed in on which we are now working will enable us to reduce the gas radiation effects, and we hope then to be able to identify the individual potentials of this group on one and the same curve.

In working with targets other than tungsten, it is to be remembered that in the course of impact measurements in an apparatus of this type the filament material is unavoidably sputtered on the target and consideration must consequently be given to the possibility that the observed radiation may be characteristic of this coating of filament material. In experiments on tungsten this difficulty is, of course, avoided.

The comparison, which can be made graphically by reference to Fig. 3, of the experimental results here obtained with those observed or deduced by Hjalmar or Bohr and Coster, shows that impact measurements in these relatively long waves serve equally with the photographic observations of workers in the short-wave regions to support the consequences drawn from Bohr's new theory of the atom. Since it seems at present that measurements of the kind described here must be largely depended upon to give us checks on theories of the structure of the outer parts of the atom, the work is being continued. It is particularly intended to measure the wave-lengths of the radiations from metals by the magnetic method as proposed when the apparatus was originally designed by Richardson and Bazzoni.

Synthetic Margarin.—In the physiological oxidation of fatty acids in the animal body, they undergo oxidation at the carbon atom which is in the beta position to the carboxyl group. Thus stearic acid yields beta hydroxystearic acid and beta ketostearic acid, then palmitic acid, carbon dioxide and water. This cycle is repeated until the entire fatty acid has been completely oxidized. However, the fatty acids of the edible fats and oils always contain an even number of carbon atoms. In diabetic acidosis, their oxidation proceeds normally until beta hydroxybutyric acid and aceto-acetic (diacetic) acid are produced, then almost ceases. These two acids combine with the bases of the blood, deplete its reserve alkalinity, and thereby produce the acidosis. A fatty acid with an odd or uneven number of carbon atoms in its molecule never gives rise to these acids but yields lactic acid, which is then completely oxidized under normal conditions. In pathological conditions, the body may fail to oxidize lactic acid, but then converts it into dextrose which is excreted. Therefore odd carbon fatty acids cannot produce acidosis; and an odd carbon fat would be of great value as a food for diabetics. Such a fat has been found in synthetic glyceryl trimargarate, or margarin, the glycerol ester of margaric acid $C_{17}H_{34}O_2$. This fat has the formula $(C_{16}H_{33}COO)_3C_3H_5$. Its manufacture and dietetic use are described by MAX KAHN (*Am. J. Med. Sciences,* 1923, **166,** 826–833). Stearic acid is subjected to the action of an oxidizing mixture, which causes oxidation to occur at the alpha carbon atom and thereby produces margaric acid. This acid is purified, then combined with glycerol to form margarin. This compound is a creamy white, odorless, tasteless, neutral substance which melts at 38° C. It is quite palatable when cold and granulated, does not produce nausea, satisfies the craving for fat, is 90 per cent. absorbed, and may be eaten *ad libitum.* It has been used, with excellent results, as a food in the diet of diabetics.

The manufacture of synthetic margarin is also discussed by RALPH H. MCKEE (*Ind. and Eng. Chem.,* News Edition, 1923, 1, No. 16, 1–2). It is also called intarvin. The cost of production was $300 per pound for the first two pounds made. This cost has now been reduced to such an extent that a seven-ounce package sells for approximately $4. Intarvin means intermediate fat. Possibly this name has been adopted to distinguish the true margarin from the commercial oleomargarin, which is a mixture of the glycerol esters of several even carbon fatty acids. J. S. H.

New Antiseptic.—J. W. HOWARD and F. D. STIMPERT (*J. Am. Chem. Soc.,* 1923, **45,** 3106–3108) have prepared the double salt of aniline and zinc chloride. It has the formula $(C_6H_5NH_2)_2.ZnCl_2$. Its bactericidal action is greater than that of either zinc chloride or aniline. J. S. H.

THE TERMINAL VELOCITY OF PARTICLES OF POWDERED COAL FALLING IN AIR OR OTHER VISCOUS FLUID.*

BY

JOHN BLIZARD, M.Sc.

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THE terminal velocity acquired by a particle of powdered coal falling in the combustion chamber of a furnace is an important factor determining the rate at which the particle burns, for the higher the velocity the more rapidly will a fresh supply of oxygen be brought to its surface. It determines also the velocity at which a current of air must move upwards in order to carry with it particles of coal of desired fineness from a pulverizing mill. The terminal velocity is thus of general importance to the designers of powdered coal plants, and this report endeavors to show how the velocity is affected by the size and density of the particle and the density and viscosity of the gaseous medium in which it falls. The conclusions reached may, moreover, be applied to estimate the velocity with which small particles other than coal fall in fluids if it may be assumed that these particles have the same shape and roughness as the particles of coal.

When a body falls in a viscous fluid it must, in displacing the fluid and rubbing against it, lose a part of its velocity until it reaches its "terminal velocity." [1]

Some idea of the form of the physical equation showing the terminal velocity with which a particle of coal falls through a viscous fluid, like air or other gas of uniform density, may be obtained by using the principle of homogeneity of dimensions.[2]

* Published by permission of the Director, Bureau of Mines, Department of the Interior.

[1] A brief theoretical discussion of the resistance of a medium, such as air, to the motion of bodies through it, will be found in the article on Mechanics, page 976, 17, "Encyclopædia Brittanica," eleventh edition. See also chapter VII, Motion in a Resisting Medium, in "A Treatise on Dynamics of a Particle," by Tait and Steele, Macmillan & Co.

[2] For a general discussion of this principle see Rayleigh, *Nature*, **95**, 66, 1915; see also, E. Buckingham, *Trans. Am. Soc. Mech. Eng.*, **37**, 263, 1915; P. W. Bridgman, "Dimensional Analysis," Yale University Press, and articles on Friction (in particular "The Resistance of Spheres," p. 369) and "Dynamical Similarity" in the Dictionary of Applied Physics, Vol. 1, The Macmillan Co.

When using this principle all the quantities involved and their dimensions are first set down and are then used to form a physical equation, both sides of which must be of the same dimensions. In an absolute system of dynamical measurements the independent fundamental units commonly used in specifying the quantities involved are those of mass, length, and time, which will be denoted by the symbols M, L, and T, respectively, and in the following table the dimensions of the quantities are given in terms of M, L, and T.

Name of quantity.	Symbol.	Dimensions of the quantity.
Velocity	U	$L\,T^{-1}$
Linear dimension of particle	a	L
Density of particle	D	$M\,L^{-3}$
Density of fluid medium	d	$M\,L^{-3}$
Kinematic viscosity of fluid medium	V	$L^2\,T^{-1}$
Acceleration due to gravity	g	$L\,T^{-2}$

These quantities might include others representing the roughness and shape of the particle, and the size and shape of the boundary of the space through which they fall, but here it will be assumed that the particles are of similar shape and roughness, so that their size is completely described by a single dimension a, and that the boundary has no effect on their velocity. Experience shows that for velocities as low as those attained by masses falling in air freely under gravity, the air is but slightly compressed in front of the particle, and it is unnecessary to consider the elasticity of the fluid. Nor will the specific heat and heat conductivity of the fluid play any sensible part in the terminal velocity of fall.

The time and acceleration are not considered because we are endeavoring to find the velocity after the acceleration has become zero, or the " terminal velocity."

All the above quantities and their dimensions are familiar, except perhaps, that of viscosity, which is thus defined by Maxwell:[3] " The viscosity of a substance is measured by the tangential force on the unit area of either of two horizontal planes at the unit of distance apart, one of which is fixed, while the other moves with the unit of velocity, the space between being filled with the viscous substance."

The dimensions of the viscosity are thus the dimensions of tangential force per unit area ($M\,L^{-1}\,T^{-2}$) multiplied by the

[3] " Theory of Heat," Longmans Green and Co., 1902, p. 305.

dimensions of the distance apart of the planes (L) and divided by the relative velocity ($L\,T^{-1}$) of one plane to the other. They are, therefore,

$$\frac{M}{L\,T^2}\cdot\frac{L}{1}\cdot\frac{T}{L}=\frac{M}{L\,T}.$$

For our purpose, however, it is more convenient to use the viscosity measured in the kinematic way, so that the unit of mass is that of unit volume of the substance itself. Thus the dimensions of the kinematic viscosity are ($M\,L^{-1}\,T^{-1}$) divided by the density of the fluid ($M\,L^{-3}$) and are ($L^2\,T^{-1}$).

The terminal velocity (U) is thus a function of the linear dimension of the particle (a), the density of the particle (D), the density of the fluid (d), the kinematic viscosity of the fluid (V), and the acceleration due to gravity (g), or

$$U=f\,(a,\,D,\,d,\,V,\,g)\,.$$

This physical equation [4] must consist of terms which are all of the same dimensions, which can be true only if the equation is of the general form

$$U^m=\Sigma\,N\,g\,a^n\,D^p\,d^q\,V^r \qquad (1)$$

in which the N's are pure numbers and the m, n, p, q, r of each term have a set of values which give each term the same dimensions as that of U. There may be any number of terms, but for each of them a dimensional equation $(U^m)=(g\,a^n\,D^p\,d^q\,V^r)$ must be satisfied.

We have, therefore, the dimensional equation:

$$(L\,T^{-1})^m=(L\,T^{-2})(L)^n(M\,L^{-3})^{p+q}(L^2\,T^{-1})^r$$

whence

for the indices of (M),	$p+q$	$=0$
for the indices of (L),	$m-n+3p+3q-2r$	$=1$
for the indices of (T),	$m\qquad\quad -r$	$=2$

and therefore, $m=2+r$; $\quad p=-q$; $\quad n=1-r$.

[4] The method followed here is that of Buckingham; see "Windage Resistance of Steam Turbine Wheels," Bureau of Standards Scientific Paper, S 208 (1914).

If these values of m, q, and n be substituted in equation (1), we have

$$U^{2+r} = \Sigma N g a^{1-r} D^p d^{-p} V^r$$

and on rearranging

$$U^2 = g a \Sigma N \left(\frac{V}{aU}\right)^r \left(\frac{D}{d}\right)^p$$

which may be written

$$\frac{U^2}{ga} = F\left(\frac{Ua}{V}, \frac{D}{d}\right) \qquad (1)$$

this equation states that the dimensionless term $\frac{U^2}{ga}$ is an arbitrary function of the two dimensionless variables $\frac{Ua}{V}$ and $\frac{D}{d}$; and the size of any two of these three products will definitely fix the size of the third.[5] The exact form of this function must be decided by experiment, but no empirical equation used to express the results of the experiments can be generally correct, unless expressed in the form of the above equation.

For very small values of $\frac{Ua}{V}$, effects of the inertia of the fluid are insensible and the resistance of the medium will therefore be independent of its density. The resistance then becomes some function of U, v, and a, where v, the ordinary viscosity ($M L^{-1} T^{-1}$), is used instead of the kinematic viscosity V, and when the terminal velocity is reached, this resistance is equal to the effective weight of the body, or $ka^3(D-d)g$, which is the excess of the gravity of the body over its buoyancy, ka^3 representing the volume of the body.

Since resistance has the dimensions ($M L T^{-2}$) it is obvious

[5] Buckingham, work cited, A.S.M.E. paper, states in reference to this method: "Further we know that any empirical form (6) which cannot be expressed in form (7) cannot be generally correct, no matter how good an approximation it may be over a limited range of experiments." The form (6) is given in terms of five original quantities, and (7) in terms of three independent dimensionless variables.

from dimensional reasoning that when the terminal velocity is reached and equal to U:

$$ka^3(D-d)g = cUva$$

where c is some unknown constant, and

$$U = \frac{k}{c}\frac{D-d}{v}ga^2.$$

This is a form of Stokes'[6] law which is for spheres of radius a,

$$U = \frac{2}{9}\frac{D-d}{v}ga^2.$$

But when the size a or velocity U becomes sufficiently large, experiment shows that it is independent of the viscosity (V) of the medium, and the equation (1) becomes

$$\frac{U^2}{ga} = F\left(\frac{D}{d}\right).$$

The terminal velocity with which similar particles fall in a particular fluid will thus be proportional to the square of their linear dimensions when very small and to the square root of their linear dimensions when large, that is to say, it will be proportional to a^n where the exponent n lies between 2 (for small bodies) and $\frac{1}{2}$ (for large bodies). Further, for small bodies falling in a fluid of density small compared with that of the particle, the density of the fluid has no effect on the velocity of the fall, while for large bodies the velocity of the particle is independent of its viscosity.[7]

A valuable series of experiments has been carried out recently by M. E. Audibert[8] to determine the terminal velocity of particles of coal of density 1.3 (water = 1), anthracite of density 1.5, and coke of density 1.9 in hydrogen, coke-oven gas, and air. These experiments have been made use of by the present writer to determine a suitable form for the dimensionless equation (1)

$$\frac{U^2}{ga} = F\left(\frac{D}{d}, \frac{Ua}{V}\right).$$

[6] Stokes, "On the Effect of the Internal Friction of Fluids on the Motion of Pendulums," *Camb. Trans.*, t. 9, p. 8 (1851), (Papers, C. iii, p. 1), also "Hydrodynamics," Lamb, Camb. Univ. Press, 1916, p. 588.

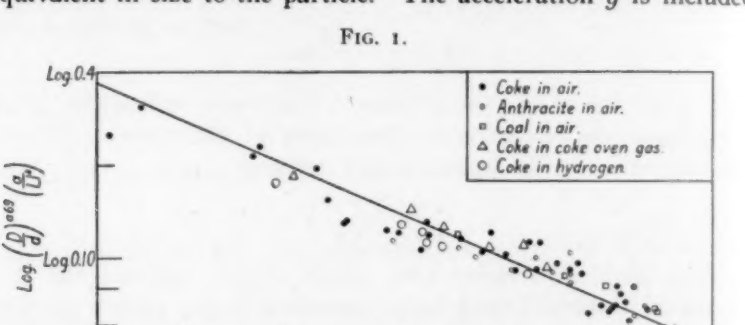
[7] "The second power of the velocity and independence of viscosity are thus inseparably connected," Rayleigh, *Phil. Mag.*, **34**, p. 59, 1892.

[8] *Annales des Mines*, 12th series, Vol. 1, 3rd publication of 1922, page 153. "Study of the Entrainment of Powder by an Air Current," M. E. Audibert.

The equation found to represent the experiments (Fig. 1) with fair accuracy is $\frac{a}{U^2}\left(\frac{D}{d}\right)^{\cdot 69} = 6.9\left(\frac{V}{Ua}\right)^{\cdot 825}$, from which it may be seen that the velocity U may be expressed by $U = \frac{a^{\cdot 9}}{3.4\,V^{\cdot 31}}\left(\frac{D}{d}\right)^{\cdot 44}$.

In the above, U, D, and V are in c.g.s. units, the density of the gas is expressed as a ratio of the density of air, and the linear dimension a is the radius in microns (10^{-4} cm.) of a sphere equivalent in size to the particle. The acceleration g is included

FIG. 1.



in the final equation as a constant. This equation holds only for values of $\frac{Ua}{V}$ between 1000 and 100,000, where a is measured in microns, although it can probably be used without great error somewhat beyond this range.

Since powdered coal falls in a furnace through gases at a high temperature and therefore higher viscosity and lower density, it is important to see whether the terminal velocity will be materially affected by the temperature. In the equation: $U = \frac{a^{\cdot 9}}{3.4\,V^{\cdot 31}}\left(\frac{D}{d}\right)^{\cdot 44}$, only d the density and V the viscosity of the gases are affected by the temperature.

Then for a particular particle in a particular gas the equation may be written $U = \frac{K}{d^{\cdot 44}V^{\cdot 31}}$ where K is a constant.

Sutherland's[9] formula for the viscosity of a gas at $A°$ C. absolute is $v = v_0\,\frac{273 + C}{A + C}\left(\frac{A}{273}\right)^{\frac{3}{2}}$, where v_0 is the coefficient of

[9] *Phil. Mag.* (5), **36**, 1593, p. 507.

viscosity at 0° C., the kinematical viscosity at $A°$ C. is, therefore, where V_0 is the kinematic viscosity, at 0° C.

$$V = V_0 \frac{273 + C}{A + C}\left(\frac{A}{273}\right)^{\frac{1}{2}} \frac{A}{273}.$$

On substituting this value for viscosity and expressing the density also as a function of the temperature, the equation: $U = \frac{K}{d^{.44} V^{.27}}$ becomes $U = K' A^{.075}\left(1 + \frac{C}{A}\right)^{.27}$ where K' is a new constant.

For air [10] $C = 124$ and the change in velocity for a change in temperature of 1000° C. is practically negligible, as may be verified by computation, thus:

Temperature °C. abs. A	$A^{.075}$	$1 + \frac{C}{A}$	$\left(1 + \frac{C}{A}\right)^{.27}$	$\frac{U}{K'}$
273	1.217	1.454	1.11	1.35
850	1.268	1.148	1.04	1.32
1800	1.300	1.069	1.02	1.33

Actually the velocity decreases slightly to a minimum value between 800 and 900° C. and then increases again slightly. In the discussion of the experiments on page 189 of the paper previously referred to on the entrainment of powder by a current of air by considering the density of the gases only and entirely neglecting the effect of viscosity, the empirical formula, $U_t = U_0\left(1 + \frac{1.91\,t}{t + 2500}\right)$, is given where U_t is the terminal velocity for a temperature of $t°$ C. and U_0 for a temperature of zero degrees centigrade, and the ratio of the two velocities for various temperatures becomes

t°C.	0	:	400	:	800	:	1200	:	1600
$\frac{U_t}{U_0}$	1	:	1.26	:	1.45	:	1.62	:	1.74

This will be seen to be in direct disagreement with the analysis of the same experiments when viscosity is taken into account. As pointed out before, empirical formulas, unless based on the rational dimensional factors involved, can lead easily to errors as in the present interpretation of results of experiments.

When powdered coal enters downwards into a furnace at a velocity of about 100 feet per second, the terminal velocity will not be immediately attained. If, however, the air into which the

[10] "Physical and Chemical Constants," Kaye and Laby, Longmans Green and Co., 1919, p. 32.

coal is injected can be considered still it can easily be shown that a velocity very close to the terminal velocity will be attained after the coal has fallen through only a few inches.

From a consideration of the equation representing the previously mentioned experiments of M. Audibert, the resistance of a particle may be taken to be approximately proportional to $kU^{1.6}$ and $\frac{dU}{dt} = g - kU^{1.6}$, where k is a constant, which shows that the velocity U will tend asymtotically to be reduced to the terminal velocity for which $g = kU^{1.6}$.

For any particular size of particle, k can be found from the terminal velocity experiments, and used to determine the resistance at higher velocities, though not without some error, since at the entering velocities the resistance varies probably as the square of the velocity.

Neglecting this discrepancy, then where S represents the distance travelled in the positive direction measured downwards.

$$\frac{dU}{dt} = g - kU^{1.6}$$

$$U\frac{dU}{ds} = g - kU^{1.6}$$

$$\int_{U_1}^{U_2} \frac{U\,dU}{g - kU^{1.6}} = S_2 - S_1$$

where $S_2 - S_1$ represents the distance travelled for a change in velocity of $U_2 - U_1$ from which

$$S_2 - S_1 = \left[\frac{10}{16}\left(\frac{g}{k}\right)^{\frac{5}{4}}\frac{1}{g}\left\{\text{Log } e\,\frac{1+\left(\frac{kU^{1.6}}{g}\right)^{\frac{1}{4}}}{1-\left(\frac{kU^{1.6}}{g}\right)^{\frac{1}{4}}} + 2\tan^{-1}\left(\frac{kU^{1.6}}{g}\right)^{\frac{1}{4}} - 4\left(\frac{kU^{1.6}}{g}\right)^{\frac{1}{4}}\right\}\right]_{U_1}^{U_2}$$

where $\left(\frac{kU^{1.6}}{g}\right)^{\frac{1}{4}}$ is less than unity.

If $\left(\frac{kU^{1.6}}{g}\right)^{\frac{1}{4}}$ is greater than unity $S_2 - S_1 = \left[\frac{10}{16}\left(\frac{g}{k}\right)^{\frac{5}{4}}\frac{1}{g}\cdot\right.$

$$\left.\left\{\text{Log } e\,\frac{\left(\frac{kU^{1.6}}{g}\right)+1}{\left(\frac{kU^{1.6}}{g}\right)-1} + 2\tan^{-1}\left(\frac{kU^{1.6}}{g}\right)^{\frac{1}{4}} - 4\left(\frac{kU^{1.6}}{g}\right)^{\frac{1}{4}}\right\}\right]_{U_1}^{U_2}$$

And a particle of 40 microns radius entering with a velocity of 100 feet per second may be shown from this formula to be reduced to practically its terminal velocity after travelling a few inches.

Summary.—In summing up the results of the dimensional analysis of these experiments, it may be stated that $U = \left(\frac{D}{d}\right)^{.44} \frac{a^{.9}}{V^{.2}} \times \frac{1}{3.4}$ is dimensionally correct, when it is remembered that $g^{.64}$ is included in the constant, and fits with fair accuracy the experiments. The terminal velocity is therefore approximately proportional to the mean linear size of the particle, to somewhat less than the square root of density of the particle, and is not appreciably affected by the temperature of the medium.

The terminal velocities of coke powder in air varied in the experiments of M. Audibert from about one-third of a foot per second, for particles of 20 microns radius, to about two feet per second for particles of 150 microns radius. A particle of 20 microns radius has a diameter of about 0.0016 inch and one of 150 microns radius has a diameter of 0.012 inch.

For practical furnace calculations the fluid in which the gas is falling may be taken as air, though obviously before the particle has fallen far, products of combustion will be present. But in falling through a furnace the mass of the particles will diminish, and they may either swell or diminish in size so that any refinement in allowing for these products of combustion is unwarranted. It may be mentioned that the viscosity of a gaseous mixture is not necessarily the mean of the viscosities of the constituents, for the presence of a small quantity of a gas, like hydrogen, which has a low viscosity, may increase the apparent viscosity of a gas-like carbon dioxide which has a higher viscosity.[11]

The kinematic viscosity of air used in calculating the equation was taken as 0.146 $\frac{\text{cm.}^2}{\text{sec.}}$, which is a value for ordinary room temperatures.

The Potash Situation.—For many years, Germany controlled the world's supply of potash—as it did the world's supply of many other important products. The enforcement of the British blockade soon caused a scarcity, and farming interests in several parts of the world were greatly inconvenienced. The United States was a heavy buyer, and the condition caused an intensive inquiry for local sources. Several of these were found. The material was obtained from certain seaweeds, from by-products of cement works and from lakes in the

[11] Travers, "Study of Gases," Macmillan & Co., p. 287.

west. Some samples of the native material contained sufficient borax to interfere with plant growth. Potato crops were seriously affected. The renewal of commercial intercourse with Germany has brought again into play German business methods, and efforts are being made to induce farmers to avoid American potash on account of the presence of borax. A recent report of the American Chemical Society states, on the authority of Dr. John T. Teeple, that both French and American potash products are here to stay. The German monopoly is broken. Germany's assertion that it can starve or feed the world is now without foundation.

The German potash producers have made much of the injury due to borax in the Searles Lake product, but the methods of extraction have been perfected so that very little of this impurity is left, and farm experiments have shown that small amounts are not injurious, and may even be beneficial. Lima beans have been found to be materially benefited by small amounts of borax. The U. S. Department of Agriculture finds that the proportion of two pounds of borax per acre is entirely safe.

Alsace, according to Doctor Teeple, is now producing over 300,000 tons of potash per year, and at two months' notice can increase this amount to 500,000 tons, providing a market is available.

How important this is will be realized when we remember that the total consumption of potash in the world, outside of Germany, has probably never materially exceeded 500,000 tons per year, and very likely has never reached that figure, with the possible exception of 1913 and 1922. These figures mean that the German potash monopoly which existed since 1860 no longer exists, and, as far as quantity is concerned, if Germany was again shut off, the world would not necessarily be lacking its full quota of potash. H. L.

Focal Changes in Mirrors Produced by Sunlight. EDISON PETTIT. (*Astrophys. J.*, Nov., 1923.)—These experiments were conducted at Mount Wilson Observatory. "The coelostat was directed upon the sun and the focal position of the sun's image determined by means of a white card moved along a fixed millimetre scale." Seven pairs of plane mirrors of various materials, with and without artificial cooling, were examined. "The mirrors of the 150-foot and 60-foot towers, which are twelve inches thick, change focus more than a centimetre per minute continuously for about four hours." The smallest changes noted were with mirrors of pyrex glass and speculum metal. Most of the mirrors tested became concave toward the sun. This is hard to understand because the heated surface expands and would be expected to bulge outwards.

When the cooling system was in operation the change of shape of the mirrors was much reduced. A wind blowing over the mirrors had a decided effect upon the change of shape. As its velocity increased it even reversed the direction of the change in progress.

G. F. S.

THE VECTOR-RULING PROTRACTOR.*

BY

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In a previous paper [1] the present writer described a vector slide-rule for determining a vector in magnitude and position when given its components and its moment about a point in their plane. In wind-tunnel work frequently only the line of the vector has to be found. Given, for example, the lift, drag and pitching moment on an airfoil or a complete airplane model, only the line of the resultant air force is to be drawn. This can be done without knowing the magnitude of the force, as will be shown, by use of a circular protractor and guiding straight-edge along which it can move.

The theory, structure and working of an instrument of this kind are presented in the following text, slightly revised from a report written for the Bureau of Aeronautics in November, 1921, when the protractor was devised by the present writer. The instrument was made in the winter of 1922, and since has been in constant service in the Aerodynamic Laboratory. The computations and drawings for it were made by Mr. L. H. Crook.

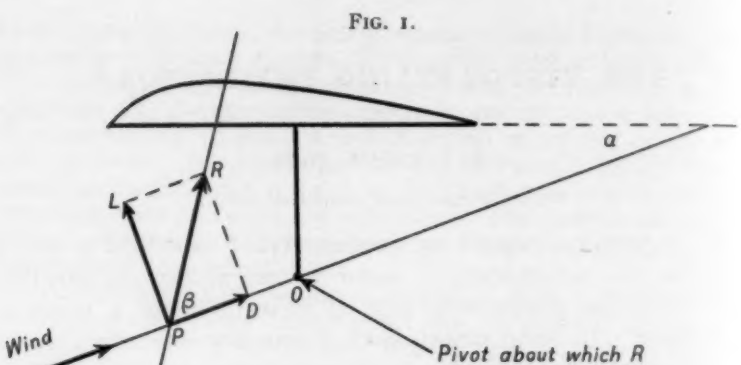
In Fig. 1, for any angle of attack α, of the wind on an airfoil of given chord line, let the lift L, drag D, and moment M about the pivot O, be known. Then a line through O, parallel to the wind, cuts the line of the resultant air force R, at a distance $OP = M/L$. The slope of the air force to this wind line is L/D. To draw the line of R, therefore, one may first pass a construction line through O parallel to the wind, then intersect it at a point P, distant M/L from O, by a second line sloping L/D to the first.

The locating and drawing of this vector is conveniently done with the aid of the instrument shown in Fig. 2. It is simply a large Colby protractor with an L/D scale added to its inner circle. This L/D or slope circle, twenty-four inches in diameter, rotates within a holding circle graduated to degrees. The diametral ruler

* Communicated by the Author, Associate Editor of this JOURNAL.

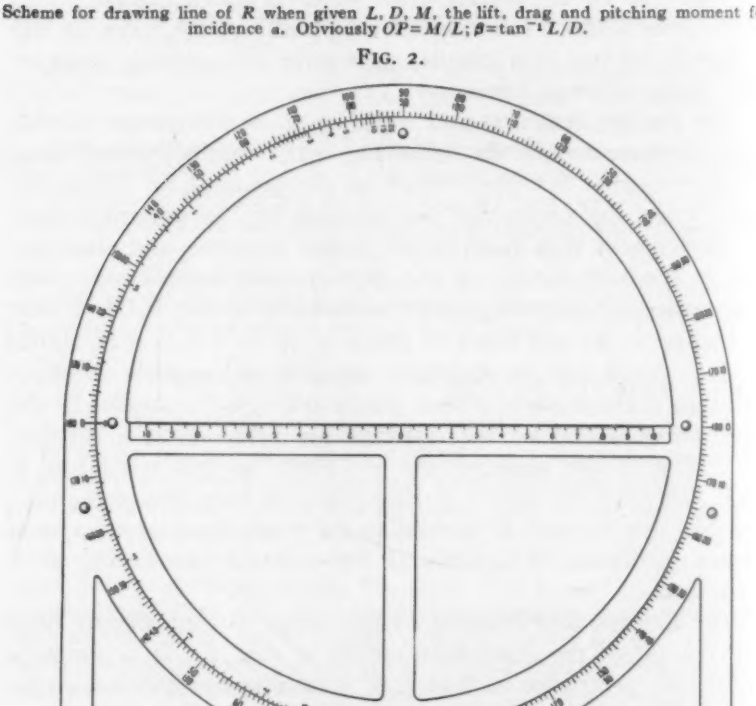
[1] "The Vector Slide-Rule," JOUR. FRANK. INST., April, 1921.

FIG. 1.



Scheme for drawing line of R when given L, D, M, the lift, drag and pitching moment for incidence a. Obviously $OP = M/L$; $\beta = \tan^{-1} L/D$.

FIG. 2.

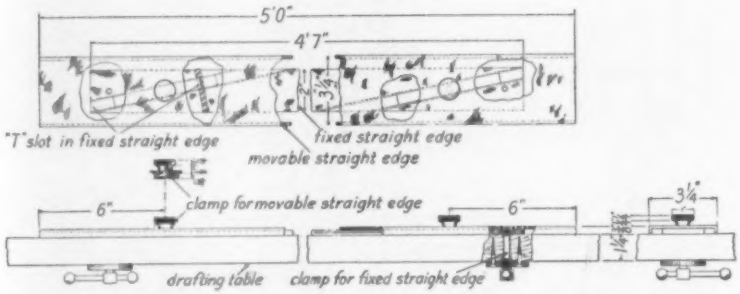


The vector-ruling protractor.

is divided in inches, tenths and fiftieths, up to ten inches each way from the centre. The whole protractor is made of German silver, and slides along a horizontal guide at its base.

This guide should be movable parallel to itself for convenience in translating the protractor crosswise of the drawing table. To effect such translation quickly and accurately a cover straight-edge (Fig. 3) is made to slide along two oblique parallel grooves cut on a 20 per cent. slope near the ends of a lower fixed straight-edge, which itself is bolted to the table and serves to clamp the drawing paper. To operate, one grasps a knurled clamping knob on the upper straight-edge, pushes to the right till the transverse displacement of the protractor is precisely correct, then twists

FIG. 3.



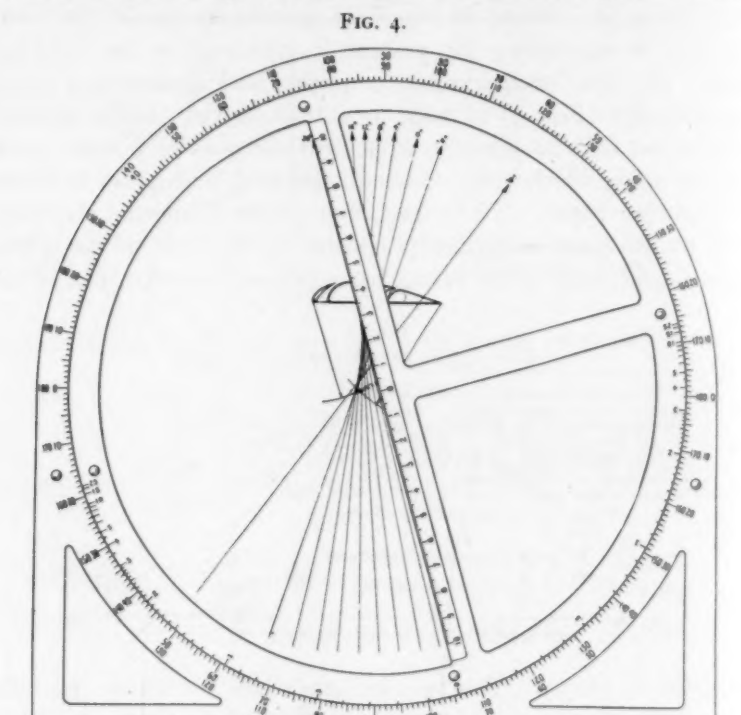
the knob to clamp. The two straight-edges constitute, in fact, an accurate parallel ruler having a mechanical purchase of 5 to 1.

To use the protractor, rest it against the straight-edge, which previously has been placed on a sketch of the airplane or other model, and parallels the wing chord; shift the straight-edge cover till it pushes the centre of the protractor up to a level with the centre of moments used in testing the model, such as the point O in Fig. 1; incline the linear scale α degrees, to align it with the wind, and along it mark a guide point, P, distant M/L from said moment centre. Next give the linear scale a slope L/D to the wind, shift it to the guide point, and draw along it the line of R. This completes the operation for one vector.

The operator may sometimes find it convenient to locate the guide point for R from given values of D or R instead of L. It is therefore worth noting that $M = Lx = Dy = R\sqrt{xy}$, since the distance from the pivot O to the vector R is x along wind, y across wind.

For example, when the vector is nearly parallel to the wind, x becomes too large, and therefore one marks the guide point on R at the distance $y = M/D$ across wind from the pivot. Then,

FIG. 4.



Method of drawing airfoil vectors.

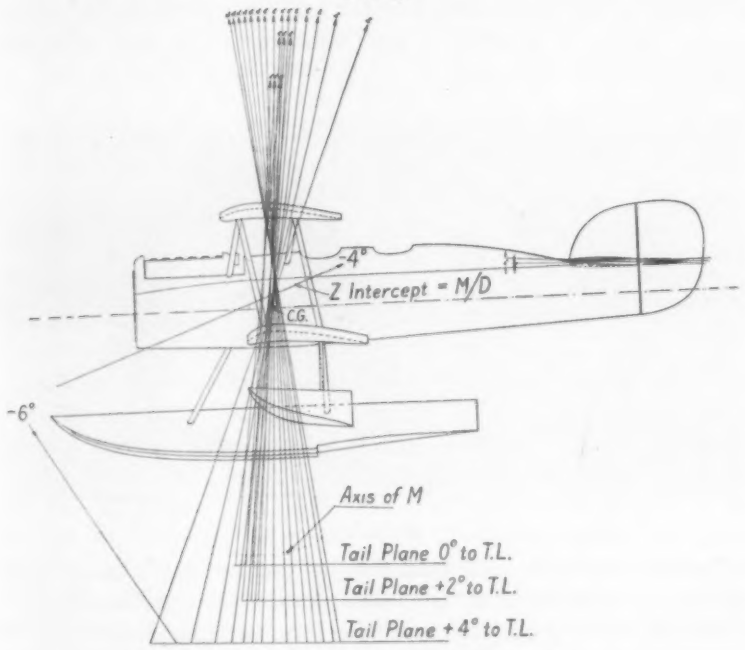
as before, the linear scale is sloped L/D to the wind, shifted to the guide point, and used as a ruler to draw R.

The usual textbook way to locate the line of R when given L, D, M, is to compute $R = \sqrt{L^2 + D^2}$, then at the distance $r = M/R$ from the moment centre draw a line whose inclination β to the wind is given by $\tan^{-1} \beta = L/D$. The foregoing method is briefer.

Fig. 4 shows the protractor resting against its straight-edge, in the process of drawing the force vectors for a slotted wing with trailing-edge flap. The diametral ruler coincides with the

line of resultant air force for an angle of attack of 30°, for which the lift drag, derived from the wind-balance readings, is about 4, and for which, therefore, the slope of the ruler to the wind must be 4. The point marked 4 on the L/D circle is accordingly set to 30° on the outer circle, which latter measures the angle of the wind to the wing chord. The ruler edge passes through a guide point previously marked on the paper at a distance M/L,

FIG. 5.



Working diagram made with vector protractor.

measured along the wind direction, from the pivot or centre of moments for the vector system. This centre of moments, at the heavy dot in Fig. 4, has the same position relative to the wing as had the pitching axis during the wind-tunnel test.

In passing one may note that the little dots mark the successive guide points used in drawing the vectors. These dots outline a curve whose equation can be found if desired. Thus the polar equation is $r = M/L = f(\alpha)/f_1(\alpha)$, where r is the radius vector, drawn from the centre of moments as origin, and α is both the angle of attack and the polar angle measured from a polar axis

fixed parallel to the wing chord. Wind-tunnel tests usually give f and f_1 as linear functions of α for the more usual flying angles.

The envelope of the vectors is also a curve the form of whose equation is well known.

In Fig. 5 is shown a typical vector diagram developed during the test of an airplane model, and superposed on the airplane sketch, made by pricking through a working blueprint then tracing with a pencil. The initial tailplane setting was slightly too low, causing the first trial vectors to fall too far forward with respect to the centre of gravity. The stabilizer angle was therefore

FIG. 6.

The protractor in use.

increased, and gave new trial vectors further aft, but not sufficiently so. A third setting, dictated by the previous results, gave a suitable vector grouping, and therefore was used for a complete set of measurements at many angles of attack. The actual moment axis used in the test is seen to be well below the nominal full-scale centre of gravity indicated by the letters *c.g.* in the diagram.

Thus by employing a ready means of sketching the air forces on a model during a wind-tunnel test much time is saved from month to month. Formerly three days would be spent, with the indirectly measuring Eiffel balance, in making preliminary tests of an airplane model at various incidences and tail settings; three days more in computing the characteristics and drawing the vector diagrams; another day in writing a report and suggesting

to the designing staff that the tailplane be raised or lowered by a small amount. Upon approval of the designing staff, communicated after due consideration, the wind-tunnel man would make a new tail setting and repeat the former operation. To-day this preliminary measuring and adjusting, which used to consume more than a week, is effected by the engineer of tests in less than one hour.

Such vector diagrams, though not indispensable, are very useful and frequently employed. When they are required the present method of drawing them can be recommended.

Fig. 6 shows the operation of drawing the line of the wind force for an airship hull held at various angles of attack. The lift, drag and pitching moment of the wind on the model had just been measured in an air stream of forty miles an hour in the tunnel, thus enabling the tunnel engineer immediately to furnish the designing staff a vector diagram for the bare hull. The test was then repeated with the same hull provided in succession with manifold types of tail fins and rudders. A new diagram was drawn for each combination, so that the most suitable control could be chosen.

The contour in Fig. 6 represents the hull of the *Shenandoah*, America's greatest airship. The wind forces and moments on the model were measured first with the hull bare, then in succession with nine different sets of tail fins and rudders. In the complete test several angles of attack were used, and wind speeds of 20, 30, 40, 50, 60 miles an hour. The laboratory report comprised about seventy tables and diagrams giving the air forces and moments acting on the ship, under manifold conditions, and disclosing the relative merits of the different types of control surface. Thus the designing staff was supplied with data enabling it to forecast the stability of the great vessel in flight, and the power required to propel her at all available velocities.

Hydrogen-ion Concentration of Magnesium Hydroxide Suspensions.—R. B. SMITH and P. M. GIESY (*J. Am. Phar. Asso.*, 1923, 12, 955–957) have determined the hydrogen-ion concentration of the aqueous suspension of magnesium hydroxide, known as magma or milk of magnesia, electrometrically. They have also calculated the hydrogen-ion concentration from the solubility product of magnesium hydroxide. The two methods yielded the same value P_H 10.51. J. S. H.

Colorado Coal.—The Interior Department has just issued a report (Bull. 748, U. S. Geol. Sur.) on the Twentymile Park district of the Yampa coal field, in Routt and Moffat Counties, northwestern Colorado. The Twentymile Park district includes only the southeastern part of this great field, but that is now its most important part, as it contains all the commercial mines that have been developed in the field. It is also generally regarded as containing the more valuable coals of the field, except the anthracite, which is found along the eastern margin of the field farther north, where, on account of the ruggedness of the surface, access to transportation lines is difficult. The mines in the Twentymile district have been developed since the Denver and Salt Lake (Moffat) Railroad was extended into this district, in 1906. The coal has become widely and favorably known as an excellent fuel for both manufacturing and domestic use, but the development of mines has been greatly hampered by inadequacy of transportation facilities and by the fact that all the coal reaching the market had to be hauled up steep grades over one of the highest passes in the Rocky Mountains. The report gives full information regarding the chemical composition of the coal and its heating value as determined by the Bureau of Mines. This value is compared with the heating values of competing or possibly competing coals, so that the consumer, if he cares to do so, may balance one coal against another and thus be able to select that which will give the greatest return for his money. H. L.

The Action of Light on Metal Electrodes in Weak Solutions. R. AUDUBERT. (*Comptes Rendus,* Oct. 29, 1923.)—As long ago as 1843 E. Becquerel found that certain electrodes were affected by the action of light. In Audubert's experiments two plates of the same metal, gold, platinum, silver, copper, placed in an electrolyte, were joined to an indicator of difference of potential. One plate was illuminated by red light or by light from the blue end of the spectrum. In order to avoid local action the side of the illuminated plate away from the other electrode was covered with an insulating coating. Owing to the action of the incident light a "photovoltaic electromotive force" of from 6 to 50 millionths of a volt manifested itself, instable and difficult of exact reproduction but surely present.

No matter what electrolyte was used the illuminated surface was always the anode for platinum, copper and mercury and the cathode for gold and silver, so long as changes of the electrolyte or of the electrode have not masked the effect. In all cases the effect of blue light was greater than that of the red end of the spectrum. For red light the sensitiveness of the metal to light action grows less as the concentration of the solution becomes greater. The effect varies little with the particular electrolyte used and is independent of the anion in the solution. The nature of the cation does, however, have some influence. G. F. S.

THE TIDAL AND CURRENT WORK OF THE COAST AND GEODETIC SURVEY.*†

BY

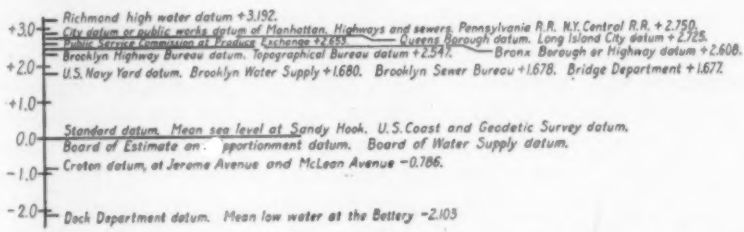
G. T. RUDE.

Lieutenant-Commander, U. S. Coast and Geodetic Survey; Chief, Division of Tides and Currents.

MEAN SEA LEVEL.

The use of automatic tide gauges in obtaining a continuous series of tidal observations over long periods is resulting in an accurate determination of mean sea level and other tidal planes

FIG. 10.


Richmond high water datum +3.192.
+3.0
City datum or public works datum of Manhattan, Highways and sewers, Pennsylvania R.R. N.Y. Central R.R. +2.750.
Public Service Commission at Produce Exchange +2.659
Queens Borough datum. Long Island City datum +2.725.
Brooklyn Highway Bureau datum. Topographical Bureau datum +2.547.
Bronx Borough or Highway datum +2.608.
+2.0
U.S. Navy Yard datum. Brooklyn Water Supply +1.680. Brooklyn Sewer Bureau +1.678. Bridge Department +1.672.
+1.0
Standard datum. Mean sea level at Sandy Hook. U.S. Coast and Geodetic Survey datum.
0.0
Board of Estimate and Apportionment datum. Board of Water Supply datum.
Croton datum, at Jerome Avenue and McLean Avenue −0.786.
−1.0
−2.0
Dock Department datum. Mean low water at the Battery −2.103

Comparison of various arbitrary datum planes with mean sea level datum plane.

in all parts of the world. One of the important phases of the tidal work of the Survey is the determination and establishment of tidal planes of reference. Formerly surveyors and engineers made use of arbitrary or local datum planes, which frequently makes it impossible to compare the results of recent with previous surveys [10] and, further, leads to confusion in the junction of contiguous surveys. To obviate the confusion resulting from such practice, the Survey has been establishing and furnishing to engineers datum planes, based on tidal definition, along all the coast line of the United States. As an example, all the datum planes shown in Fig. 10, except *mean sea level*, are arbitrary and

* Presented at a meeting of the Mechanical and Engineering Section of The Franklin Institute, held Thursday, February 8, 1923.

† Concluded from the January issue, p. 97.

[10] W. Bell Dawson, "Method of Investigation of Tides and Currents," *Trans. Roy. Soc. of Canada*, vol. iv, section III, Third Series, 1910, pp. 14–15.

cannot be reproduced if the bench marks be destroyed. To obviate possible loss of these arbitrary datum planes the Survey is connecting by precise level nets these different datum planes of other organizations and cities to its mean sea level datum. Thus, any of these various planes may be reproduced years hence, even should their bench marks be lost.

In its geodetic work the tidal plane of mean sea level has been carried to many parts of the interior of the country by a network of precise level lines, having as its initial and "tie-in" points a mean sea level plane determined at the principal tidal stations along the seaboard. On the Atlantic coast long series of observations are being obtained at Portland, Boston, New York City, Breakwater Harbor at the entrance to the Delaware River, Philadelphia, Atlantic City, Baltimore, Charleston and Fernandina; on the Gulf coast, at Key West, Cedar Keys, Pensacola and Galveston, and on the Pacific, at San Diego, San Francisco, Seattle and Ketchikan, Alaska. The observations at these stations are all connected with permanent bench marks for the use of engineers locally, or for the initial or "tie-in" points for precise level nets. In this connection the Survey has recently issued a publication containing the descriptions and elevations of some 1800 tidal bench marks in New York State, referred to datum planes based on tidal definition. This publication will be followed by similar ones for other sections of the coasts and should prove of considerable value to engineers engaged on construction of docks, bridges and harbor improvement, or other marine work.

The value of a tidal datum as a plane of reference lies in its simplicity of definition as well as in the certainty with which it may be reproduced at some future time, if lost because of the destruction of all bench mark connections. A low water plane is the most satisfactory for the purposes of the mariner, because by its use a chart will show the least depth which he may expect regardless of the stage of the tide. The plane of mean low water has therefore been adopted on hydrographic charts for the whole of the Atlantic coast; on the Pacific coast, because of the diurnal inequality of the tides, the plane of mean lower low water is used; that is, all soundings shown on charts of the Coast and Geodetic Survey have been reduced, no matter what the stage of the tide at the time the soundings were made, to a mean low water

plane on the Atlantic coast, and in general to mean lower low water on the Pacific coast and Alaska.

Planes determined by high waters or higher high waters are at times adopted for other engineering purposes, but the most satisfactory plane in general is that of mean sea level, since it is the most easily determined of all the tidal planes and also since the other tidal planes may be derived from it by a knowledge of the range of tide and of its diurnal inequality. The planes of mean low water, mean high water or mean higher high water, etc., are all local, since they depend upon the range of the tide at a given place; that is, these planes when extended from place to place along a coast would be, if visualized, a wavy or rolling plane, while mean sea level may be considered as an equipotential surface forming a continuous, smooth plane. Mean sea level may be defined, then, as that level at which the waters of the oceans would come to rest if freed from all disturbing influences of tides, wind, weather, and varying barometric pressures.

Since these conditions do not exist, it was necessary to devise some means for determining what this level would be. And it is important to note that the only means for determining this is by observations of the rise and fall of the tide. The hourly heights of the tide, tabulated from this record of observation, are averaged over the entire period. The result is known as mean sea level and the accuracy of its determination is defined by the length of the series of observations. The series must be of sufficient length to have passed through varied meteorological conditions and atmospheric pressures, or corrected for variations due to these causes.[11]

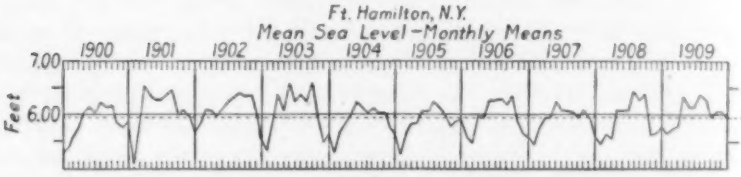
For practical purposes a tidal plane obtained from a month of observations may be considered as *fairly* well determined. Planes, determined at different times, however, may differ considerably because of long period tides, seasonal changes, differences of atmospheric pressures from month to month, or year to year, and these conditions made it necessary to have long-continued observations such as are made by the Survey at its principal tidal stations.

That the determination of mean sea level is not an altogether

[11] John F. Hayford, "Effects of Wind and Barometric Pressures on the Great Lakes," Carnegie Institute of Washington, 1922.

simple matter and one that can be determined by short series of observations is brought out by Fig. 11, which is a diagrammatic representation of the plane of sea level as determined by uncorrected monthly means, from 1900 through 1909, at Fort Hamilton, New York. The broken horizontal line represents mean sea level, which reads 5.96 feet on the tide staff as determined from a long series of tidal observations. This graph shows variations from month to month as large as a foot and a half.

FIG. 11.



Diagrammatic representation of the plane of mean sea level, determined from uncorrected monthly means, 1900 to 1909, at Fort Hamilton, New York.

The seasonal variation, too, is very evident, being much higher in summer than in winter for each year throughout the period.

While sea level as determined by a series of observations extending over only a month may differ as much as a foot or more from that determined for another month, the level as determined by observations extending over a period of a year may differ as much as a quarter of a foot from a level determined during another year. It is evident, therefore, that for a very accurate determination of mean sea level for geodetic and other scientific work even a year is not sufficient.

A graph (Fig. 12) of mean sea level by yearly means over the period of 1912 to 1920 for our principal tidal stations along the entire Atlantic coast, preliminary to an exhaustive study of the subject, has brought out the interesting fact that the causes for a yearly variation of sea level from a mean sea level determined by many years of observations are not local; that is, the conditions causing the yearly variation certainly extend along the entire Atlantic Sea Board. For the year 1919 the sea level at Portland (Fig. 12) was thirteen-hundredths of a foot above the long period mean sea level; at Fort Hamilton, twenty-two hundredths above; at Atlantic City, seventeen-hundredths above; and so on down the entire coast to Fernandina, Florida. Fig. 12 shows also

that there was a depression of the level of the sea along the coast from 1916 to 1918, while in 1915 we have another maximum, depressing again toward the year 1912. I have cited the year 1919 first because the variation was largest for that year and so nearly uniform along the entire coast.

It should be borne in mind that these plottings have been made from actual, uncorrected observations, and it is very likely that further study of the subject will show a correlation between these variations and the variation in mean atmospheric pressure over the ocean from year to year. Observations have been made for a number of years to determine the effects of winds and barometric pressures on the level of the Great Lakes and a publication [12] of the results has been issued recently.

It is evident that the subject is worthy of further investigation and should form an interesting paper in itself in addition to having a marked practical value. The mere plottings alone on cross-section paper to a large scale, as shown in Fig. 12, have considerable practical value; for example, let us suppose we have one year of tidal observations at Boston during the year 1919 and desire the nearest value to a mean sea level at that place from that single year of observations. Since it is clearly evident that the sea level along the entire North Atlantic coast that year was above the long period mean sea level, we may very safely assume this to have been also true at Boston. Choosing ports nearby, we have at Portland that year the level 0.13 foot above the long period mean sea level; at Fort Hamilton, 0.21 foot above, or a mean of the two of 0.17 foot. Adding another station we have 0.13 foot above at Portland; 0.21 foot above at Fort Hamilton, and 0.17 foot at Atlantic City, or again a mean of 0.17 foot. It is probable therefore that a very close value of mean sea level for Boston may be obtained by subtracting 0.17 foot from the level obtained from the observations made at that place in the year 1919.

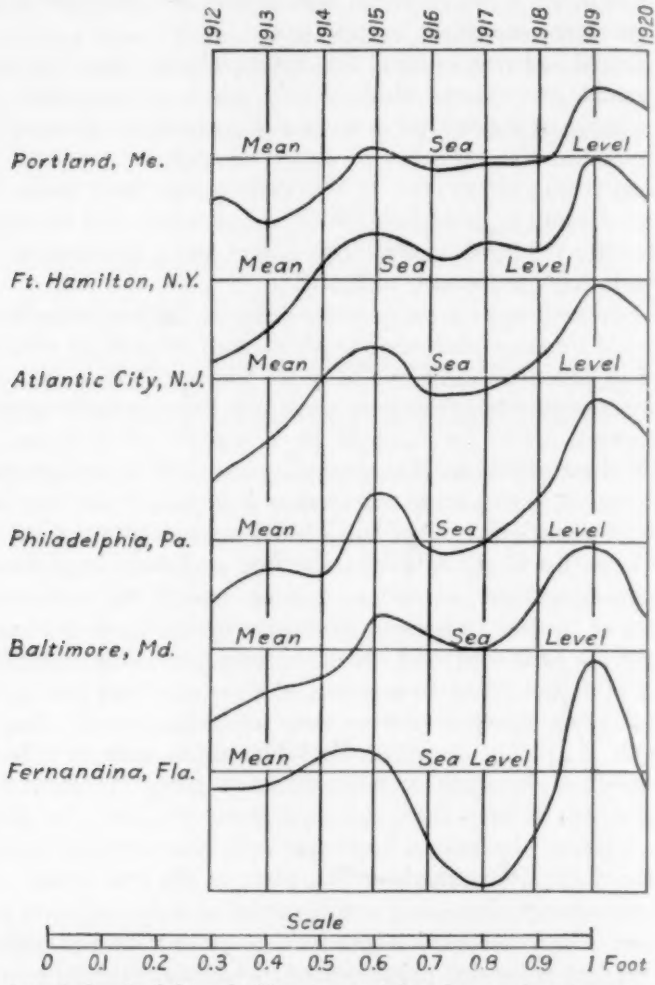
I have attempted to bring out the value of mean sea level to the engineer; a very accurate determination of this natural standard for a vertical reference point is also of considerable value to the scientist. To quote from a recent paper: [13] "It is therefore

[12] John F. Hayford, "Effects of Wind and Barometric Pressures on the Great Lakes," Carnegie Institution of Washington, 1922.

[13] R. L. Faris, "Some Problems of the Sea," *Jour. Washington Acad. Sci.*, vol. xii, No. 5, March 4, 1922, p. 127.

important that the relation of the land elevations to the sea level be studied and accurately known. A knowledge of this relation

FIG. 12.



A graph of sea level, determined from uncorrected yearly means (1912 to 1920) at principal tidal stations. Compared with a long period mean sea level.

is vital to the study of the subsidence and emergence of land areas."

Now, if observations extending over a year determined accu-

rately mean sea level, the difference in this plane between two years would measure the rate of change in this relative elevation. But the problem is not quite so simple; for mean sea level, as illustrated by Fig. 12, is subject to long period variations, part of which may be due to long period tides as well as to variations in mean yearly barometric pressure over the oceans, all of which requires further study.

When mean sea level has been obtained from observations extending over centuries, *quantitative* evidence will be available of the stability of coast lines of continents by reference of bench marks to this mean sea level.

The principal tide stations of the Coast and Geodetic Survey are so placed as to be representative of a region and to furnish tidal control for these regions. In addition to serving this purpose the continuous observations covering a number of years bring out the changes in mean sea level, thus furnishing data for a quantitative determination of relative changes in elevation of land and water.

Some scientists claim that a subsidence of the Atlantic coastal plain is taking place and have advanced considerable qualitative evidence tending to bear out this belief.[14] Quantitative evidence, however, is needed, and plans which are being formulated to extend over a long period of years will probably finally furnish *quantitative* data as to the rate of change, if any. Of course, since any rate of change will be very inconsiderable, its determination is not a matter of decades, but of a century or more. The observations should be planned and carried out systematically by this generation and passed on to the next.

It may be said, of course, and possibly with reason, that we cannot know anything definite about the variations in mean sea level; that is, the variations in the relation between a well-determined mean sea level and the coast. We must either assume, therefore, that the level of the sea remains constant and that any changes relative to the sea coast are due to the subsidence of emergence of the land and not to a change in mean sea level; or possibly definite knowledge of a quantitative nature may be obtained to establish the constancy of the level of the sea, as well

[14] Douglas W. Johnson, "Is the Atlantic Coast Sinking?" *Geographical Review*, vol. iii, 1917, p. 135.

as the vertical movement of the sea coast by plans illustrated by Figs. 13 and 14.

Fig. 13 is a representation of mean sea level, young coastal plain, and geologically older interior of the continent just back of the coast. The Survey's bench marks maintained at principal tidal stations on the coast are represented by the cross on the right; the cross at the base of the mountains represents bench marks, which have been already installed or are planned. Now, making no assumption as to stability of the coast or constancy of mean sea level, any difference which may be shown to exist between mean sea level and these coastal bench marks, after long series of tidal observations, will be relative; in other words, has the land subsided or emerged, or has the mean elevation of the sea undergone a change? Now, then, by placing other bench

FIG. 13.

General representation of mean sea level, young coastal plain and geologically older interior of continent.

marks in the geologically older formations back of the coastal plain and connecting the two systems of bench marks each decade by precise levels, it should be possible to determine by their relation just what is taking place, a permanent change in mean sea level or a change in the elevation of the coastal plain.

Fig. 14 shows the distribution of our principal tidal series along the Atlantic and Gulf coasts of the United States, the open circles representing long series which have been discontinued; the solid circles, stations with long series and still maintained. The various symbols over the irregular areas represent the relative geologic age of these areas, the quarternary or more recent along the coast, back through the areas of different ages to the pre-cambrian, represented by the heavier hachures. The system of broken lines represents the present precise level nets along the coast which have been already run. The precise levelling now in progress and proposed will connect the bench marks at all the principal tidal stations along the coast with bench marks on land relatively older geologically. Comparison of the results of these lines of levels, re-run systematically between coastal bench marks and those on older formations inland, should furnish *quantitative*

evidence not only of any variation, but also whether due to change in the elevation of the sea coast or to a raising or lowering of mean sea level.

FIG. 14.

Distribution of principal tidal series along the Atlantic and Gulf coasts of the United States and precise level net connecting these series.

EARTHQUAKE WAVES.

The "Tidal Wave" of the headliners is in no sense a tidal wave; it is a sea wave due to a seismic disturbance.

Very destructive seismic sea waves have occurred in regions subject to earthquake disturbances throughout historical times; among others, the destruction of Helike in 373 B.C.; at Callao in 1724 and 1746; at Libson in 1755; Arica in 1868; Iquique in 1877, and on the Japanese coast in 1896.

Waves eighty feet in height have been reported in some places

near the origins of seismic disturbances. These waves are propagated for considerable distances over the oceans, at times reaching the shores of other continents, though with constantly diminishing amplitudes.

In connection with the velocity of propagation of seismic sea waves, a brief study has been made of the fluctuations on the tidal marigrams from several of the Survey's principal tidal stations, brought about by the earthquake which occurred on November 11, 1922, off the coast of Chile.

The sea waves caused by this earthquake were recorded on the tidal marigrams at Honolulu, San Diego, San Francisco and Zamboanga, Philippine Islands. Tracings of the marigrams from the tidal stations at San Diego, San Francisco and Honolulu are shown in Fig. 15. Before the tracings were made the records were all reduced to Greenwich Civil Time, November 11–12, 1922.

It will be noted that the curve at the beginning of the tidal graph for each station has only minor fluctuations caused by wind wave effects; the remainder of the curves, however, have distinct, sharp fluctuations of considerable amplitude.

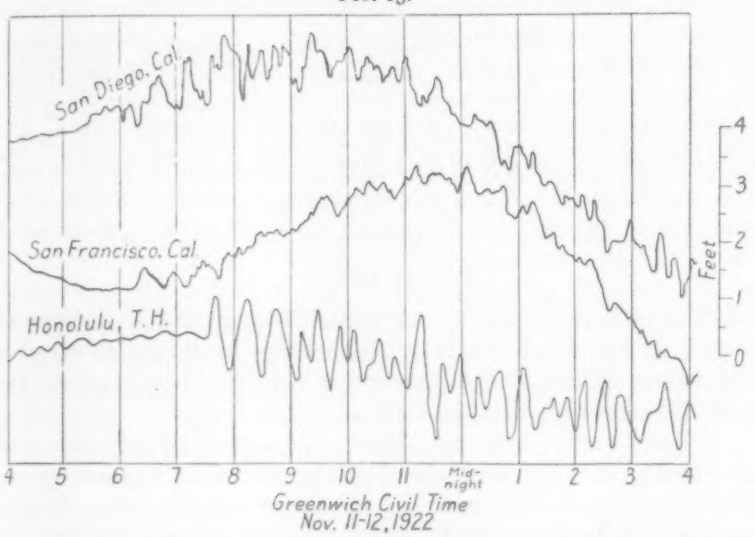
Computations, based on the records from the seismographs maintained at Honolulu, Territory of Hawaii; at Sitka, Alaska; at Tucson, Arizona; at Cheltenham, Maryland, and at Vieques, Porto Rico, indicate that the earthquake occurred on November 11th at $4^h\ 33^m$ A.M. (Greenwich Civil Time), and that its origin was on the coast of South America in the vicinity of Carrizal, Chile, at about 28° south latitude.

The tidal graph for San Diego (Fig. 15) shows that the first fluctuation due to the seismic sea wave began on November 11th at $5^h\ 30^m$ P.M. (Greenwich Civil Time) and recorded a maximum amplitude about two hours and twenty minutes later, with a range of 1.2 feet and with a period of from thirty to forty minutes. Assuming that the propagation of the seismic wave began at the origin of the earthquake simultaneously with the first earth tremor, the time of transmission of the sea wave from Carrizal to San Diego is twelve hours and fifty-seven minutes, or at the rate of 346 miles per hour for an average derived depth of water of 1750 fathoms. San Diego is about 4480 miles from Carrizal.

The first distinct fluctuation on the graph for San Francisco indicates that the sea wave arrived at that station at $6^h\ 20^m$ P.M. (Greenwich Civil Time), or fifty minutes later than at San Diego.

It reached a maximum amplitude of about 1.1 foot range about eleven hours later and its principal oscillations had a period of thirty to forty minutes. The time of transmission of the wave from the origin of the earthquake to this station is thirteen hours

FIG. 15.



Records on the marigrams of the tidal stations at San Diego, San Francisco and Honolulu of seismic sea waves from the earthquakes which occurred off the coast of Chile, November 11, 1922.

and forty-seven minutes, or at the rate of 356 nautical miles per hour for an average derived depth of water of 1880 fathoms. San Francisco is 4890 nautical miles from Carrizal.

At Honolulu, the first fluctuation began on November 11th at 7^h 30^m P.M. (Greenwich Civil Time), and reached a maximum amplitude about four hours later, with a range of 2.2 feet. The graph shows that the oscillations at this station were sharp and regular and had a period of twenty to thirty minutes. The time of transmission of the wave from Carrizal to this tidal station is fourteen hours and fifty-seven minutes, or at the rate of 390 miles per hour with an average derived depth of water of 2250 fathoms. Honolulu is 5850 miles from Carrizal.

The seismic sea oscillations at each of these stations continued from three to four days, gradually diminishing in amplitude and finally disappearing from the record.

The following tables give data on the propagation to our tidal stations of the seismic waves from the earthquake near Carrizal, Chile.

November 11, 1922, Origin near Carrizal, Chile.
Occurred at 4:33 A.M. (Greenwich Civil Time).

Tidal Station.	Distance from Carrizal. (Naut. Miles)	Green. Civ. Time. Arrival of Wave.	Time for Transmission of Wave.	Naut. Miles per Hour.	Derived Depth of Ocean.* (Fath.)
Honolulu, T. H.	5850	Nov. 11, 7:30 P.M.	$14^h\ 57^m$	390	2250
San Diego, Calif.	4480	Nov. 11, 5:30 P.M.	$12^h\ 57^m$	346	1750
San Francisco, Calif. .	4890	Nov. 11, 6:20 P.M.	$13^h\ 47^m$	356	1880
Zamboanga, P. I.	9350	Nov. 12, 6:45 A.M.	$26^h\ 12^m$	357	1890

*Mean depths computed from Table 51, "Manual of Tides," Part III, R. A. Harris.

TIDAL POWER.

A general paper on the subject of tides would be incomplete without at least brief reference to the energy in the ceaseless rising and falling of the vast volume of water on the surface of the earth, brought about by the tides.

While a study of the possibilities of power from utilization of tidal energy and the methods of production of this power is not a function of the tidal work of the Coast and Geodetic Survey, the Division of Tides and Currents of the Survey has kept in touch with literature dealing with the subject in order to answer the requests for information addressed to the Bureau as the tidal authority in this country.

The economical harnessing on a large scale of the energy in the tides has been the dream of the engineer for centuries; but, unlike fire, steam, the water-power of streams, and electricity, it has been the last force of nature not enslaved by man. As compared with coal and oil, the initial cost of the necessary construction and installation has rendered the use of tidal power generally out of the question. When nations find it essential to begin by some means to conserve the fuel supply, engineers may find an inexhaustible source in the tides if they are successful in economically harnessing this power. Should they be successful we shall in time probably see many projects, introduced by countries, states and corporations, or even counties and municipalities, situated favorably from a standpoint of large range of tide. By that time, however, the engineering difficulties will have been com-

letely overcome and the necessary machinery developed to its highest state of efficiency.

Plans for the utilization of power from the tides have been rejected by many engineers as involving too great initial cost in the construction of reservoirs in proportion to the amount of power obtained. It must be borne in mind, too, that in practice it is not possible to obtain the full theoretical power, nor to utilize the vast power of all the oceans, but only that small fraction of tidal power available near the coast where natural facilities permit empounding small parts of the sea and constructing power plants.

The Civil Engineering Department of the British Ministry of Transport has prepared plans for the utilization of tidal power in the estuary of the River Severn, where the range of tide is from twenty to thirty feet.[15] The English propose building a dam for empounding the waters of the Severn and using this dam also as a bridge for railway and vehicular traffic, connecting South Wales with the remainder of the country. The combining of the two projects will partly lower, of course, the initial cost chargeable to the tidal project. And this initial cost has previously been considered the vital objection.

The utilization of tidal power has also received attention from French engineers and a number of schemes have been proposed for the development of this power. The range of tide on the northwest coast of France lends itself to such schemes. The mean ranges along the coast bordering the Bay of Biscay vary from 12.7 feet at the mouth of the Gironde River to 14.3 feet at Ushant Island; and along the coast on the English Channel, 16.6 feet at Isle de Bas to 26.8 feet at St. Malo, decreasing to the northward to 16.2 at Cape Griznez, Strait of Dover.

The harnessing of the tides for power purposes has been approached heretofore on a much smaller scale than now proposed by the British and French. Tide mills of small power for grinding corn have been in existence for many years in Spain on the shores of Andalusia, on the Thames, in the Isle of Wight and on the Bay of Fundy. These mills, however, are far from modern and have an efficiency only about 10 per cent. of the theoretical power. In all these cases the range of tide is considerable, a necessary factor for the success of any tidal power plan. Means for furnish-

[15] "One Million Horsepower from Tidal Energy," *Scientific American*, January 22, 1921.

ing power during the time the tide is rising or at a stand is another important factor, too, in tidal power development.

Should engineers be successful in economically harnessing the tides, their use on the Atlantic coast of the United States would be limited to northern New England, because of comparatively small ranges of tide elsewhere. At Calais, St. Croix River, Maine, the mean range is 20.0 feet, decreasing gradually southward along the coast to 10.5 feet at Bar Harbor, Mount Desert Island. In Penobscot Bay the mean range varies from 9.1 feet at Head Harbor, Isle au Haut, to 13.1 feet at Bangor, Penobscot River. South of Penobscot Bay the mean range is less than 10 feet along the entire Atlantic coast with the exception of Wellfleet, Cape Cod, where it is 10.7 feet.

CURRENTS IN GENERAL.

Accompanying the vertical movement of the water caused by the tidal forces of sun and moon, a horizontal movement also takes place, giving rise to currents in the water. Since the primary object of the current work of the Survey is for the purposes of navigation, the importance of these currents to the mariner and engineer are emphasized in this discussion.

Fig. 16 [16] will serve to illustrate and to emphasize the importance to the mariner of adequate knowledge of coastal currents. This sounding line was plotted from the record log of a Survey vessel engaged on offshore hydrographic work and was not exaggerated for the sake of emphasis. The *dashed line* shows the course of the vessel plotted according to "dead reckoning," no allowance being made for currents; the *full line,* the course of the vessel plotted according to dead reckoning, with allowance for set of the vessel by currents. The vessel was anchored at the positions indicated by circles and the direction and velocity of the current observed at these anchorages.

It should be stated, however, that the actual time from the beginning to the end of the line of soundings was about thirty hours.

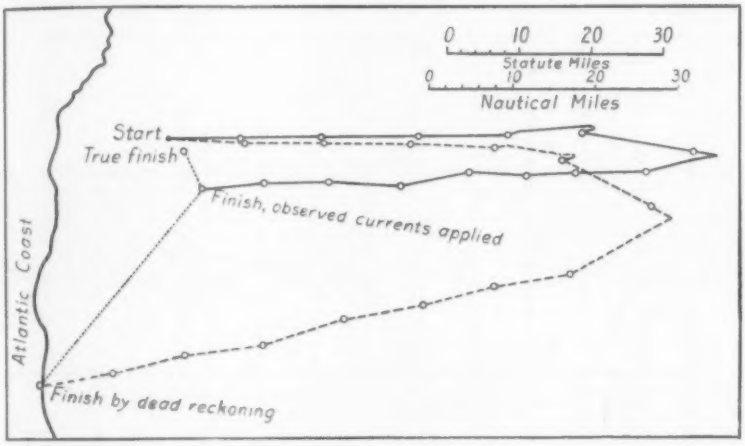
In addition to those currents due to astronomical forces working through the tides, others are brought about by meteorological conditions and physical differences in sea water in different

[16] E. Lester Jones, "The Neglected Waters of the Pacific Coast," Government Printing Office, 1918, Plate 5.

parts of the oceans. These astronomical forces, combined with terrestrial conditions, as in the case of the tides, give rise to several types of currents which are described in detail hereafter:

(1) The rectilinear or reversing type, illustrated by the currents in most inland bodies of water, such as Chesapeake Bay and Hudson River; (2) the hydraulic type, illustrated by the currents in straits connecting two independently tided bodies of water; for example, the East River, New York, and Seymour Narrows,

FIG. 16.



The effect of currents on ship's position.

Alaska; (3) the rotary type, illustrated by the currents in the open ocean and along the coasts; (4) wind-driven currents of a temporary nature, produced by the effect of friction of local winds on the surface of the water; and (5) the permanent currents comprising the main ocean circulation, illustrated by the Gulf Stream of the Atlantic and the Kuro Siwo of the Pacific.

The first three types are of tidal origin and are therefore periodic, while the last two are non-periodic and are due to meteorological conditions, variations in barometric pressures over the oceans, and differences in temperatures and densities of the sea water in different parts of the ocean.

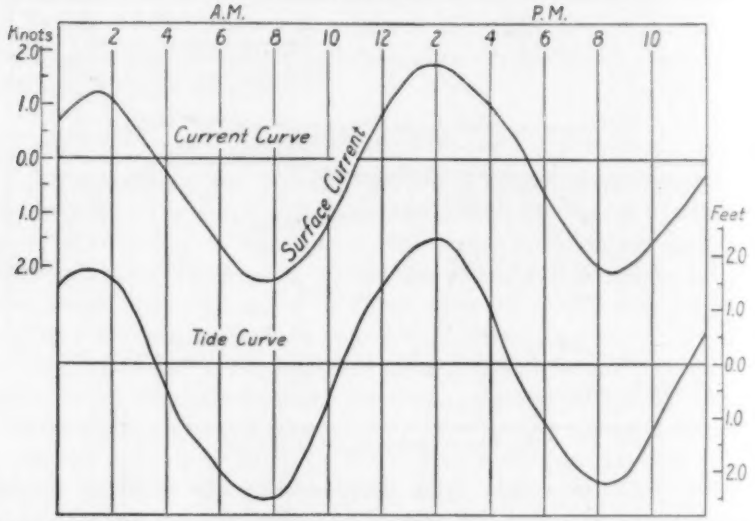
RECTILINEAR OR REVERSING TYPE CURRENTS.

The type of current known as the rectilinear or reversing type is familiar to all, since it is found in all inland bodies of water

connected with the ocean. These currents do not change in rotary fashion like the tidal current in the ocean, which is described hereafter, but come to a slack and reverse, the direction being designated flood when referring to the horizontal movement of the water toward the land or up-stream, and ebb when to the movement away from the land or down-stream.

This current is intimately related to the tidal regime of the body of water. In a body in which the tides are due to a progres-

FIG. 17.



Current and tidal curves. Current station at mouth of the Hudson River and tidal station at The Battery, Manhattan Island.

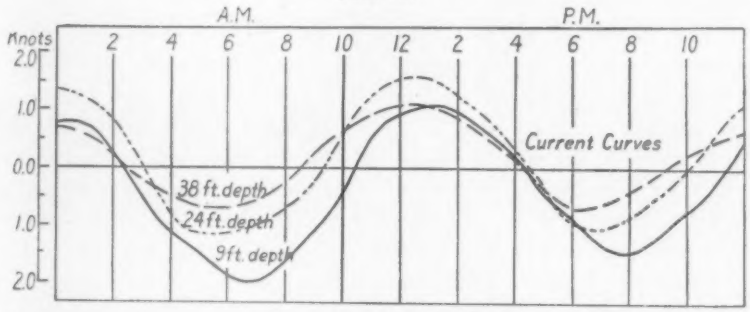
sive wave the time of the reversal of the current, slack water, occurs about half-tide, and the strength of flood and ebb about the time of high and low water, respectively; in a body which has a stationary tidal wave, slack water occurs about the time of high and low water and the greatest current velocity about the time of half-tide.

Fig. 17 illustrates this time relation for a current station in the Hudson River, which has the progressive tidal wave. The upper diagram is a graph of current observations on August 29, 1922, at a station at the mouth of the Hudson. The lower diagram is a reproduction of the tidal curve at The Battery, Manhat-

tan Island, for the same date. In both diagrams the time coördinate is in the axis of X; in the upper the Y-axis denotes velocity in knots, and in the lower heights in feet. In the upper diagram the zero horizontal line represents slack water, the flood velocity being plotted above this line and the ebb velocities below; therefore the intersection of the curve with the zero line indicates the exact instant of slack water. In the lower diagram the zero line represents mean sea level.

The parallelism of the two curves is indicative of the intimate time relation existing between the tides at The Battery, Man-

FIG. 18.



Rectilinear current curves for three depths, plotted from the records of a current station at the mouth of the Hudson River.

hattan, and the currents at the entrance to the Hudson; for example, the times of slack water (upper diagram), occurring at 2 A.M., at 10:30 A.M., and at 5:20 P.M., agree very closely with the times of half-tide at 2:35 A.M., at 10:15 A.M., and at 4:45 P.M. This occurrence of slack water at the time of half-tide is one of the indications that the tides of the Hudson are due to a progressive wave and not to a stationary wave.

While a current graph plotted in this manner furnishes, by means of the intersection of the curve with the zero horizontal line, the exact theoretical instant of slack water, in practice the term "slack water" is generally accepted to mean that period during which the velocity is less than one-tenth of a knot.

A current graph of this character has, too, an added advantage of furnishing the relation, which may be detected instantly, of the velocities of the currents at different depths. Fig. 18 is a graph of the current velocities obtained from observations at three

depths, 9 feet, 24 feet and 38 feet, on August 29, 1910, at a station in the entrance to the Hudson.

It will be noted that the slacks from flood to ebb, between 2:00 and 4:00 A.M., are very nearly at the same time at the three depths, occurring first at 9 feet, a few minutes later at the bottom-depth (38 feet), and about a half hour later at the mid-depth (24 feet). This is again true in the afternoon slacks from flood to ebb between 4:00 and 6:00 P.M., except that the times are more nearly simultaneous than those of the preceding slack from flood to ebb. The average time between the surface and mid-depth slacks of the flood to ebb at this station has been found from a long series to be twelve minutes.

The times of slacks from *ebb* to *flood* at different depths, however, have a wider range, and occur first near the bottom (8:30 A.M.), next at mid-depth (9:15 A.M.), and last near the surface (10:25 A.M.). This relation again holds for the night slack from ebb to flood—at the 38-foot depth first (9:20 P.M.), next at the 24-foot depth (10:00 P.M.), last at the 9-foot depth (11:30 P.M.). From this graph, then, the time between the slack water near the bottom and that on the surface differs by about two hours. This interval has been found to average two and a half hours at this station from a long series of observations.

To sum up for this station, the slack water following a flood occurs first on the surface and last at mid-depth, with an average interval between of twelve minutes; the slack water following an ebb occurs first at the bottom and last on the surface, with an average interval between of two and a half hours.

This difference of intervals for slacks at different depths following a flood current from that following an ebb, is due to the fact that on the flood the dense ocean water is flowing into the harbor against the lighter fresh water run-off of the river and is thus causing a commingling of the water. This action, having a tendency to bring about a uniform density of the water from top to bottom, causes the change in direction to occur practically simultaneously at all depths. On the other hand, during an ebb current, with no force to cause a mixing of the water, the dense salt water seeks the bottom and the lighter fresh water run-off seeks the surface. Now when the flood water first begins running into the harbor from the ocean, the dense ocean water hugs the bottom and underruns the fresh surface water coming down on the ebb. This

lower layer of heavy flood water therefore retards and brings to a slack, first, the lower layer of ebb current, gradually gaining sufficient momentum to offset the inertia of the overrunning, less dense, surface water.

HYDRAULIC TYPE CURRENTS.

While hydraulic type currents, which are illustrated by the currents in straits connecting two independently tided bodies of water, are reversing currents, they are due, not to tidal action of the purely stationary or progressive type, but rather are due to a temporary difference in head between the two bodies of water brought about by tidal action. The currents in the East River, New York, are examples of this type, and a brief description of them will serve to illustrate this type in general.

The East River connects Long Island Sound with New York Bay, and the tides in these two bodies of water are decidedly different. The tides in Long Island Sound are due to a stationary wave and the range of tide *increases* from 2.0 feet at Montauk Point to 7.2 feet at Willets Point, at the west end of the Sound; the tide in New York Bay is brought about by a progressive wave and the range *decreases* from 4.7 feet at Sandy Hook to 4.4 feet at Governors Island. This difference in range of tide at the two ends of the East River is sufficient in itself to produce a hydraulic gradient; but, in addition, the time of the tide at Willets Point at the north entrance to the East River is later by over three hours than the time of the tide at Governors Island at the south entrance. This difference in time is in fact the larger factor in producing the temporary difference in hydraulic head.

As examples, high water occurs at Willets Point when the tide is about mean sea level at Governors Island, and therefore the current at this time is setting to the southward through the East River; and at the time of high water at Governors Island the tide at Willets Point is about mean sea level and the current then is setting toward Long Island Sound.

This difference of tidal conditions in Long Island Sound and New York Bay, at times causing a hydraulic gradient of four feet in the distance of seventeen miles from Willets Point to Governors Island, gives rise in Hell Gate to currents which attain a mean velocity at strength of about five knots and occasionally of eight knots.

While it is a comparatively simple matter to predict the time that the heads will be equalized and that slack water should occur, with conditions such as these, account must be taken of the momentum of this mass of water and of the time of the continuance of the flow, due to this inertia, after equalization of head. This information can be obtained only from observations, and to obtain mean conditions these observations must be continued over a considerable period, since the range of the tide between springs and neaps varies more than 20 per cent. and therefore the current velocity at the different phases of the moon varies proportionately.

OCEAN CURRENTS.

While the rise and fall of the tide is of considerable importance to the mariner when on soundings, it is of no importance to him over the greater part of the world—the oceans. Currents, on the other hand, must be reckoned with both when navigating inland waters and in keeping account of position at sea by dead reckoning.

Unknown or unsuspected currents have been the contributing causes of more vessel strandings than probably any other single worry of the navigator. And in spite of this fact less attention has been given to systematic observations and study of ocean currents than has been given to any other branch of the subject of oceanography.

Three reasons may probably be assigned for this near-neglect of a phenomenon so closely associated with the subject of tides: Obviously, tidal observations may be made far more economically than current observations for which expensive vessels, with full complement of officers and crew, are necessary. Secondly, associated with periodic tidal currents are non-tidal currents, which are in general produced by the wind and are non-periodic. Data for the predictions of tidal currents, since they are periodic, may be obtained from observations extending over a comparatively short period of time, while the non-tidal, being non-periodic, require a considerably longer series of observations to furnish average conditions and to allow of predictions of any degree of accuracy. And again, another reason for this lack of systematic current observations at sea is that the oceans may be considered

the highways of commerce for all nations and therefore the study of its problems an international rather than a national undertaking.

The principal maritime nations have made current observations, however, on their inland waters and along their coasts. Predictions are made and published for the use of the mariner of those currents due to tidal action. The Coast and Geodetic Survey has within the last few years given attention to the study of coastal currents, both tidal and wind-driven. Current tables have been issued recently, containing information on this subject, which is of vital importance to the safeguarding of life and property in coastwise shipping, particularly on the Pacific coast. In the more than thousand miles of Pacific coast line from the Mexican border to the Strait of Juan de Fuca harbors are many miles apart, sailing courses long, and periods of foggy and stormy weather of comparatively frequent occurrence. And it so happens, too, that the currents on the Pacific coast, like the tides, are more complex than those on the Atlantic.

During the years from 1900 to 1917, more than a hundred [17] vessels were stranded or wrecked on the Pacific coast of the United States, involving a loss of hundreds of lives and millions of dollars in property, and this in spite of the fact that the navigators on that coast comprise an unusually able and alert group of men. To a large extent the loss was due to the lack of knowledge of the currents along the Pacific coast. The information recently issued by the Survey, and the observations still in progress, should furnish more adequate knowledge of these currents and should become a factor in preventing a considerable part of such enormous losses.

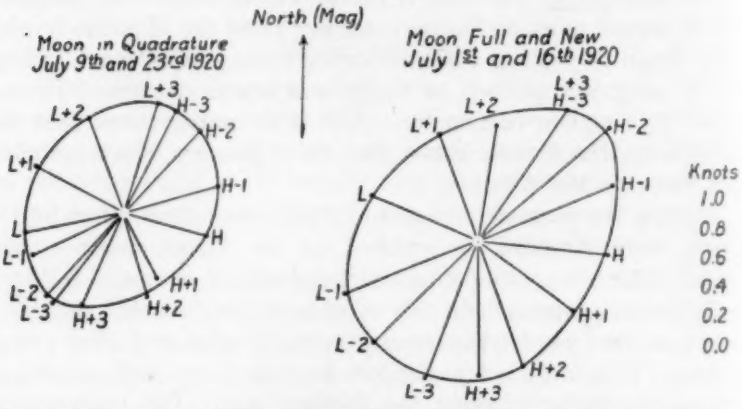
Though the total coastal current to which a vessel may be subject is made up of a combination of two components, the periodic or tidal current and the non-periodic or wind-driven, analysis of a long series of current observations made at any station serves to separate the two, so that a proper correlation may be made between each component and its causes; that is, the velocity and direction of the tidal current may be referred to the state of the tide at some standard port, and the velocity and the direction of the wind-driven current correlated with the force and the direction of the wind prevailing at the time.

[17] E. Lester Jones, "The Neglected Waters of the Pacific," Government Printing Office, Washington, 1918, Plates 10 and 11, op. p. 16.

Since the two coastal currents, though combined, are of such distinct characters, they will be taken up separately.

Coastal Tidal Currents.—During the last few years appropriations for current work of the United States, while meagre in view of the objects sought and the considerable coast line of this country, have been sufficient to permit obtaining current observations covering a period of a number of months at each of the different light vessels stationed along the coast. The results from these observations, while limited largely to the vicinities of the

FIG. 19.



Graphs of rotary, coastal tidal currents, Nantucket Shoals Light Vessel, Atlantic coast, at times of different phases of the moon.

light vessels, have warranted giving the mariner considerable new information of the general laws of coastal currents.

Since the current data obtained from the observations on the light vessels limit our knowledge of the coastal current to the vicinities of these vessels only, the Survey is making short series of observations, as funds permit, from a survey vessel anchored at critical points between and simultaneous with observations at the light vessels. A correlation of the two series will be made, looking toward obtaining average conditions at these midway critical points. Such a survey is designed to bring out the effects of both the tidal currents and the wind-driven currents along the entire coast.

On the open coast the tidal current is not of the rectilinear or reversing type, with its period of slack water; it is never slack, its direction changing constantly in a rotary movement.

The varying velocities through a tidal cycle, when plotted to scale, approximate an elliptical figure illustrated by Fig. 19, which are plottings to scale of the velocities and the directions of current observations at Nantucket Shoals Light Vessel, referred to the time of tide at Boston. The left-hand diagram is a graph on polar coördinate paper of two days of observations through one tidal cycle on July 9 and 23, 1920, at the time when the moon was in quadrature, causing neap tides; the right diagram, two days of observations through one tidal cycle at time of spring tides, which occurred on July 1st and on July 16th.

The directions of the lines indicate directions of the current and their lengths the velocities. As an example from the left diagram; at H (time of high water at Boston), the current at Nantucket Shoals Light Vessel sets about east by south, with a velocity of six-tenths of a knot; at $H + 2$; that is, two hours after high water at Boston, it sets about south by east with a velocity of six-tenths of a knot; at L (time of low water at Boston), the direction of set is about west by south, and the velocity about seven-tenths of a knot.

It should be noted that this direction is constantly changing clockwise at a rate of about 15° per hour from H through each hour to L and so on to H again, and that the velocities are of such magnitude that a curve through the extremities of the velocity ordinates fairly approximates an ellipse.

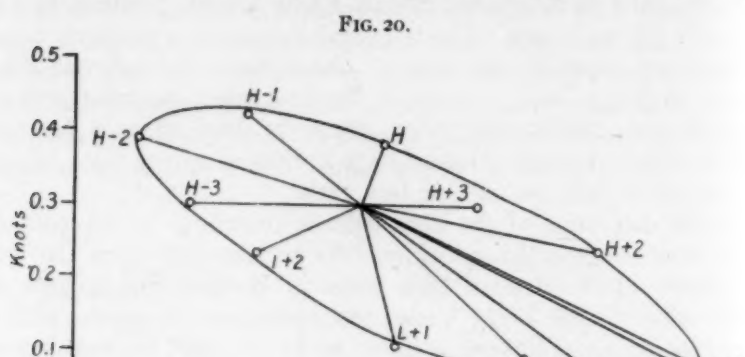
A comparison of the right and left diagrams illustrates the fact that the velocity of the coastal tidal current on the Atlantic coast varies with the times of neap and spring tides, but that the direction of the set of the current is the same at any time of the month for the same tidal hour at a standard tidal port; for example, in both diagrams H is in the same direction from the origin; at $L - 3$ (three hours before low water at Boston) the direction is the same for both diagrams, and likewise for each tidal hour.

A graph of the tidal current at Brunswick Light Vessel (Fig. 20) illustrates that coastal tide currents assume more nearly the character of the rectilinear or reversing type as the coast is approached, the ellipse becoming more elongated than those for Nantucket Shoals Light Vessel. Brunswick Light Vessel is only a few miles offshore while Nantucket is forty miles.

On the Pacific coast the coastal tidal current is also of the

rotary type; but, like the tides on that coast (lower graph, Fig. 1), they have considerable diurnal inequality. On the Atlantic coast the current velocities vary principally, as indicated by Fig. 19.

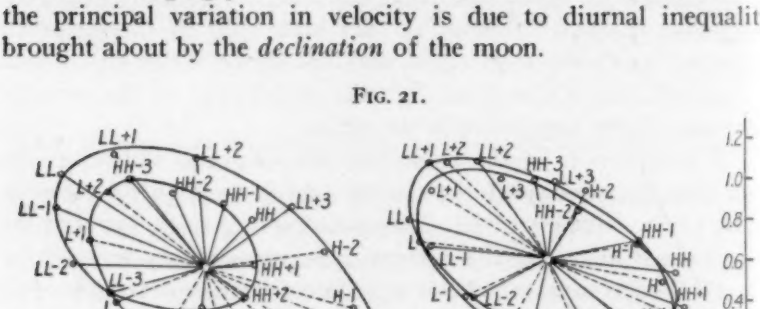
FIG. 20.



Graph of the rotary tidal current at Brunswick Light Vessel, Atlantic coast.

with the changing *phases* of the moon, while on the Pacific coast the principal variation in velocity is due to diurnal inequality brought about by the *declination* of the moon.

FIG. 21.



Graphs of rotary tidal current, Swiftsure Bank Light Vessel, Pacific coast, at times of different declinations of the moon.

Fig. 21, current graphs from the observations for the year 1919 at Swiftsure Bank Light Vessel, at the entrance to the Strait of Juan de Fuca, is representative in general of the type of coastal tidal current on the Pacific coast. The times are referred to the times of the tide at Astoria, Oregon, *H* representing the

time of high water, *L* the time of low water, *HH* the time of higher high water, and *LL* the time of lower low water. The figures 1, 2 and 3, preceded by a plus or minus sign, indicate one, two and three hours after or before, respectively, the times of the various stages of tide represented by the letters which they follow. The broken, radiating lines connect the origin of the curve with high and low water hours, and the full lines with the higher high and lower low water hours at Astoria.

The left-hand diagram, which is plotted from observations made at the times the moon was farthest north and farthest south of the equator, illustrates the variation in velocity due to diurnal inequality; that is, the daily tidal forces are at a maximum at the time of the greatest declination of the moon. Then, on the Pacific the velocity of the coastal tidal current, like the range of tide (lower graph, Fig. 1), is greater during one tidal cycle than during the next; for example (left diagram), at *H* + 1, one hour after *high* water at Astoria, the current at Swiftsure Bank Light Vessel is setting 125° (True) with a velocity of 1.03 knots; whereas, at *HH* + 1, one hour after *higher high* water at the standard port, it is setting 90° (True), with a velocity of only 0.25 knot.

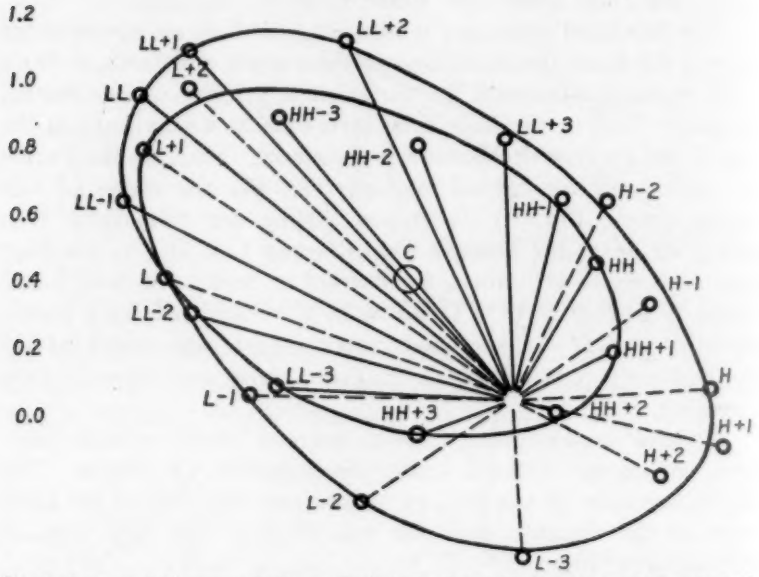
A curve drawn through the extremities of the velocity ordinates, as on the Atlantic coast, approximates an ellipse. The ellipse, however, of one tidal cycle is larger than that of the next; while on the Atlantic coast the two ellipses of a tidal day are practically the same.

Examples from the left-hand diagram may serve to illustrate its use: When the moon has its greatest declination the current at Swiftsure Bank Light Vessel at *H* (time of high water at Astoria) sets 107° (True), with a velocity of 1.0 knot; at *LL* + 3, three hours after lower low water, it sets 60° (True) with a velocity of 0.53 knot; at *L* + 1, one hour after low water, 285° (True), 0.6 knot; at *LL* − 1, one hour before lower low water, 293° (True), 0.8 knot, etc.

The right-hand diagram (Fig. 21) is a graph of the currents at the time the moon has its least declination; that is, when the moon is on the equator. At this time the semi-daily forces predominate and the diurnal inequality practically disappears from both the tides and the currents. The two ellipses, comprising the two tidal cycles, assume practically the same form and size.

While Fig. 21 represents in general the type of tidal current of the Pacific coast, the diurnal inequality at some places along the coast is more pronounced than at others. At San Francisco Light Vessel, for example, the diurnal inequality is so pronounced when the moon is farthest north or south of the equator that the tidal currents during one tidal cycle are far out of proportion to those

FIG. 22.



Graph of rotary tidal current, Swiftsure Bank Light Vessel, illustrating graphic method of determining permanent set.

of the next cycle; in fact, the small ellipse at this time almost disappears in a graph of the observations at that light vessel.

By this method of plotting the tidal current graph, the *permanent* set of the current at a station, due to other causes not tidal, may be readily obtained. Fig. 22, a graph of the tidal current at Swiftsure Bank Light Vessel for the month of August, 1919, illustrates the procedure. The velocities and directions of the tidal currents, as averaged for the particular period desired, are plotted from a common origin on polar coördinate paper and the true centre of the ellipses is determined. The direction and distance to scale of this true centre (*C*, Fig. 22) from the origin of the ellipses represents the permanent set, in this case N. 40°

W., 0.47 knot; that is, superimposed on the tidal currents, there was a constant set during the month of August, 1919, past Swiftsure Light Vessel at a rate almost half a mile per hour in a direction N. 40° W. The physical reason for this permanent set is evident from the fact that Swiftsure Bank Light Vessel is located just off the entrance to the Strait of Juan de Fuca.

The permanent set of the current at any station along the coast may be due to several causes, among which are prevailing winds, fresh water discharge from a strait or river, and permanent sets like the Gulf Stream.

Since the rotary tidal currents along the coast are so closely related to tidal action in that their velocities and directions are comparable with the times of high or low water at some standard port, it is evident that those components of coastal currents, due to tidal action alone, may be as readily and accurately predicted as tides are. Predictions may be made, then, by reference to the times of the tides at some standard port, of the direction and velocity of the tidal current for any moment at any light vessel along the coast.

The problem for the navigator, however, is not so easily solved, for this tidal current is only one of the components of the total coastal current. The other, due to the local winds, is not only non-periodic, defying accurate predictions a long time in advance, but in general is also of greater velocity than the tidal currents and therefore proportionately of greater menace to coastwise shipping.

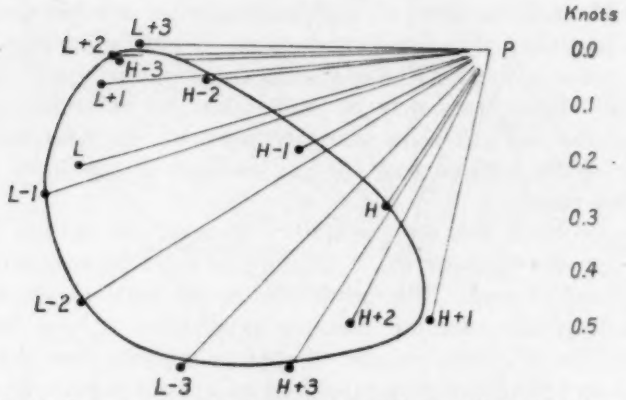
Coastal Wind Currents.—Under coastal tidal currents, Fig. 22 illustrated a permanent set, which displaced somewhat the tidal ellipse from its origin; at times the current produced by heavy winds retards the regular tidal current to such an extent that the origin is displaced considerably *outside* the ellipse. Fig. 23 is a graph of the currents at Frying Pan Shoals Light Vessel from observations made during a northeast storm, from January 29 to February 2, 1920. The wind *velocity* varied during the five days from 15 miles to 60 miles an hour and averaged 34.6 miles; the wind *direction* varied from north-north-east to north-east.

The origin of the graph is at *P* and the centre of ellipse at *C;* the length (0.57 knot) and the direction (about southwest) of a line *PC* represents the average total drift and set per hour of the current due to the storm wind component. The direction of the

current varied throughout a tidal cycle from south to west and back to south, from $H + 1$ to $L + 3$, by way of $L - 2$, and then from $L + 3$ to $H + 1$ again, by way of $H - 1$. The velocities varied, too, because of the tidal forces, throughout a cycle, and a curve through the extremities of the velocity ordinates approximated an ellipse; that is, the currents, though setting to the

FIG. 23.

Jan. 29 - Feb. 2, 1920



Graph of currents at Prying Pan Shoals Light Vessel, Atlantic coast, from observations made during a Northeast storm.

southwestward during the entire duration of the storm, varied in velocity by the amount of the acceleration and retardation due to the tidal component.

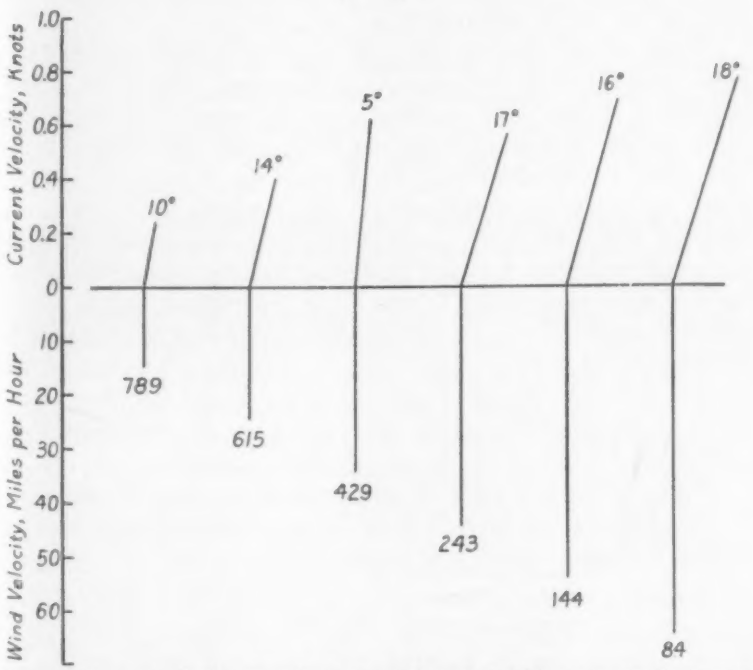
Recent investigations and the comparatively long series of continuous current observations obtained during the past few years at the different light vessels along the coasts of the United States have brought out the important fact that, contrary to the belief of the mariner, a local wind creates a current setting not in its own direction, but in a direction about fifteen degrees to the right of the wind on the Pacific coast and about twenty degrees to the right on the Atlantic coast.

Since a large number of observations of this character are necessary for averages of any degree of accuracy and also for the

elimination of tidal current in the resulting data, it is evident that the observations of wind-driven currents have to be made over a considerable period to get a number of winds of 10 miles an hour, 20 miles an hour, etc., from various points of the compass.

Fig. 24 represents diagrammatically the number of observations over a period of two years, 1919–1920, and the results

FIG. 24.



Diagrammatic representation of results of observations of wind-driven currents, due to southeast winds, at Blunts Reef Light Vessel, Pacific coast.

from a southeast wind for velocities of from 10 to 70 miles an hour at Blunts Reef Light Vessel on the Pacific coast.

The lengths of the vertical lines below the horizontal line represent the wind velocity and the numbers at their extremities indicate the number of current observations obtained with the wind at that velocity; for example, 789 current observations were made when a southeast wind was blowing from 10 to 20 miles an hour, 615 observations with a wind velocity of 20 to 30 miles, 429 observations with a wind velocity of 30 to 40 miles,

etc. The lengths of the slanting lines above the horizontal line represent the velocity of the wind-driven currents due to each respective wind velocity, and the deflection from the vertical shows the deflection of the resulting current to the right of the wind direction; for example, a southeast wind of 10 to 20 miles an hour creates an average current of 0.24 knot velocity, deflected 10° to the right or N. 35° W.; 615 observations at the times of 20- to 30-mile southeast winds show a current of 0.4 knot, deflected 14° to the right or N. 31° W., etc.

While a deflection to the right in the northern hemisphere is to be expected from theoretical considerations, due to the earth's rotation on its axis, it is modified along the coasts by configuration of the bottom, bottom friction, and form of the coast line. Therefore, while a general law may be given of the average current produced by any given wind velocity, observations are necessary at intervals along the coast, particularly well inshore, to determine the actual velocities for that particular locality. On sailing lines for coastwise navigation, however, the general law will hold with sufficient accuracy for practical results within five to twenty miles offshore. *It has been found that the velocity varies fairly proportionately with the wind velocity and is about two per cent. in knots of the wind velocity in miles per hour on the Pacific coast and one and a half per cent. on the Atlantic coast.*

Below is given a table of current velocity due to local winds on the north Pacific coast,[18] based on the observations at the light vessels stationed along this coast.

Wind velocity, miles per hour	10	20	30	40	50	60
Current velocity, knots	0.3	0.4	0.6	0.7	0.9	1.1

The importance of the discovery that the set of the current is to the right of the wind direction, lies in the fact that a wind blowing parallel with the coast produces a current which may tend to set a coastwise vessel onshore, a fact which until now has been unsuspected by the navigator. As an example, a vessel bound up the Pacific coast with a following 60-mile wind will overrun her log, due to wind-driven current alone, by one and two-tenths knots per hour and be set in toward the land fifteen degrees on the average to the right of the wind direction.

[18] Pacific Coast Current Tables, U. S. Coast and Geodetic Survey, p. 46.

In practice, of course, it is necessary to take into consideration the combination of this wind-driven current with the periodic tidal current, and to apply the resultant for correcting the course made good by a vessel. For example, a vessel, near San Francisco Light Vessel at a time when the tidal current is setting N. 15° W., with a velocity of 0.5 knot, and at the same time a wind of 60 miles per hour is blowing from S. 30° E., will be set by the combined current in a direction N. 15° W., at the rate of 0.5 + 0.9 = 1.4 knots. In actual practice, if the two kinds of currents do not happen to set in the same direction as in this case, the resultant current may be readily obtained from a diagram, drawn to suitable scale, of the velocity and direction of each component, tidal and wind-driven, the resultant direction and velocity being scaled from this graph.

At sea, particularly in coastwise navigation, constant vigilance on the part of the navigator is the only price of safety; for at times wind-driven currents of considerable velocity precede the wind to which they are due. The writer during two winters, 1915–1916 and 1916–1917, was engaged on offshore hydrographic work from the Carolinas well down the Florida coast and from the shore out to the Gulf Stream, involving current observations over this area. A number of times during this period current observations showed a strong set from the southwestward during moderate weather, considerably displacing the regular tidal current ellipse from the origin of the current graph. In every case this condition was indicative of a heavy southwest blow which followed within a few hours. At times, of course, a long swell, preceding the wind, may accompany this strong current, but sometimes even this warning of treacherous currents is absent.

This effect on the current of a distant wind has been reported, too, by fishermen on the coasts of Newfoundland and in the Gulf of St. Lawrence.[19] When at anchor offshore these fishermen take this behavior of the current as an indication of heavy weather, and, according to their statements, it is noticeable twelve hours before a storm comes on. The writer has not observed this condition preceding the blow by more than four to six hours.

While the main oceanic circulation involves a study of currents which are in general produced by predominant winds, such

[19] W. Bell Dawson, "The Tides and Tidal Streams," Ottawa, 1920, p. 41.

as the Trades, and possibly by differences in barometric pressures, densities and temperatures over the oceans, little of a quantitative nature has been done toward a systematic study of these phenomena. They will not be taken up therefore in this discussion. In fact, that which has been accomplished may be considered as a reconnaissance only, and volumes may be devoted later to a thorough study of the subject, upon obtaining the vast amount of quantitative data necessary to such a study.

From the standpoint of safety of shipping the permanent currents comprising the main oceanic circulation are not of the order of importance of those currents close in to the coasts and in inland waters, since vessels subject to the influence of these oceanic currents, or drifts, have plenty of sea room. It is probable, therefore, that this, coupled with the vastness of the undertaking of systematic current observations over the oceans, has resulted in this lack of quantitative data.

The set and drift of these currents have been mapped in a general way; but the principal information is of a qualitative nature obtained from a record of the drift of bottles and of wrecks, and from a difference between the true and the dead-reckoning positions of vessels, the determination of which does not permit of a high degree of accuracy. But all these furnish qualitative data only and quantitative data can come only from systematic observations, which may be considered an international rather than a national problem.

Another problem of considerable importance to the engineer and to the scientist alike is the study of erosion and accretion of coast lines. While volumes have been written on shore processes, much of the evidence is of a qualitative nature and here, too, data of a quantitative kind are needed, involving a thorough knowledge of tides, currents and wind-produced ocean waves.

INSTRUMENTS FOR CURRENT OBSERVATIONS.

The instruments made in the United States for the observation of currents have been devised principally for shallow depths and for use in rivers. Little attention has been given, therefore, to attachments for furnishing the direction of the current.

There are a number of types of meters, described in the catalogues of American instrument manufacturers; they are all,

however, made on a principle somewhat similar to the anemometer used by the meteorologist—several metal cups on a carriage revolving in the current and making an electric contact at each revolution of the carriage. This contact, making an audible "tick," is transmitted through insulated cable and telephone receiver to an observer on a vessel. The instrument can be used at any moderate depth desired, and in practice is generally lowered to a depth equal to two-tenths of the total depth of water, then to five-tenths of the depth and finally to eight-tenths, and observations made at each depth. Then beginning at the lowest depth check observations are made as the meter is raised to the surface.

The meter is rated before and after a survey lasting several months, so that the revolutions may be reduced to exact current velocity.

Since the meters furnished by manufacturers in this country do not give the direction of subsurface currents, an important matter in current surveys for local peculiarities of current in large ports off piers and slips, the Coast and Geodetic Survey has recently developed a device for determining the direction of subsurface currents. It is known as a "Bifilar Suspension Current Indicator," and appears to have solved in a simple and inexpensive manner a problem long of serious concern to engineers and navigators.

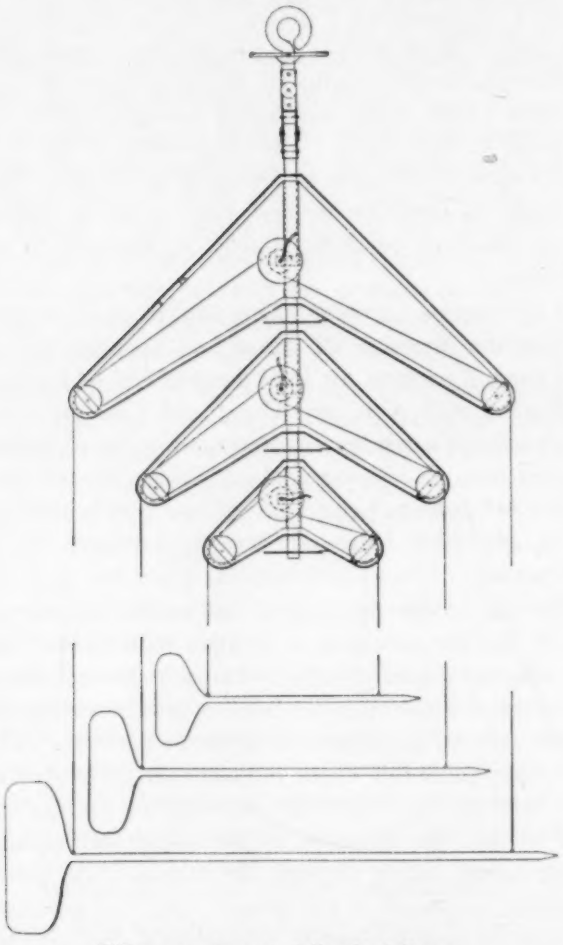
Briefly, the device as used in the recent current survey of New York Harbor consisted of a pipe, with rudder attached at one end, suspended horizontally by two fine aircraft wires from a bar, free to turn in azimuth by virtue of a ball-bearing joint at its connection with an outrigger or davit on a vessel. The pipe is lowered to any moderate depth desired. A graduated pelorus at the davit indicates by a pointer the direction of the bar, which is forced to take the direction of the subsurface current by the subsurface rudder acting through the taut aircraft wires.

A later development of the device (Fig. 25) permits not only of simultaneous observations at three depths, but also lessens the labor of operation by obviating the necessity of continually lowering and raising a single rudder for observations at various depths.

Foreign instrument makers have given consideration to attachments within the instrument for the determination of direction.

Among others are the Ekman [20] meter and the Pettersson [21] meter. The former accomplishes the purpose by allowing metal balls, the size of ordinary shot, to drop into different compartments, one for

FIG. 25.



Bifilar suspension current direction indicator.

[20] T. T. Jenkins, "A Text Book of Oceanography," E. P. Dutton, New York, p. 133.

[21] Dr. Hans Pettersson, "A Recording Current Meter for Deep Sea Work," *Quarterly Jour. Roy. Meteor. Soc.*, vol. xli, No. 173, January, 1915.

each of the principal points of the compass, as the meter swings in azimuth; the latter by photographing on a narrow, sensitized film the graduated periphery of a glass disc, which is held in azimuth by a magnetized steel bar.

The Coast and Geodetic Survey has obtained good results in the observations of surface current velocities on the light vessels along the coast by the use of the current line, which consists of the ordinary log line used in the days of the sailing ship for estimating the speed of the vessel, except that it is graduated to a sixty-second interval for use with a stop-watch instead of a shorter interval as used with the old sand-glass. The sailing ship chip log is replaced by a pole three inches in diameter and fifteen feet long, weighted with lead at the lower end to float upright with about one foot out of water. The line is graduated for the sixty-second interval from the proportion 3600 sec.: 60 sec. = 6080 feet: X, or 101 feet, 4 inches representing one knot. The knot is subdivided into tenths by means of silk fish-line tabs.

The finished products of the tidal and current work of the Coast and Geodetic Survey for the use of the engineer and mariner appear in several forms: In the Tide and Current Tables, which foretell the state of the tides and currents for any future time; in publications on tidal bench marks, which definitely fix for the engineer the various tidal planes along the coasts of the United States, and in other publications devoted to a detailed study of the tides, the currents and related phenomena in the various harbors of the country.

Potency of Commercial Vitamins.—E. M. BAILEY, HELEN C. CANNON, and H. J. FISHER (*Conn. Agric. Exp. Station Bull. 240*, 51 pp., New Haven, 1922) have made chemical and biological tests of twenty commercial vitamin preparations. Chemical examination frequently showed the presence of added medicaments such as nux vomica and phenolphthalein. In the biological tests for potency, determination was made of the presence and relative amount of water-soluble B, the vitamin which promotes growth, prevents beriberi, and possibly has other functions. Dried brewers' yeast was taken as a standard; and young albino rats were used as test animals. In these tests for potency or vitamin content, three preparations yielded excellent results and four preparations very good results; five preparations gave indifferent or inconsistent results; and eight preparations failed conspicuously. J. S. H.

Chrome Alum Light Filter.—LE ROY W. MCCAY (*J. Am. Chem. Soc.*, 1923, 45, 2958) recommends an aqueous solution of chrome alum as a light filter in qualitative analysis. A solution of 310 grams of chrome alum in one litre of water is prepared with the aid of heat, is cooled to room temperature, and filtered. Square prismatic bottles, having a lateral edge of 4.7 cm. and a height of 10 cm. from bottom to shoulder, are filled with this solution and corked. The resulting permanent filter is held upright, very close to the eye and 5 or 6 cm. from the flame. It completely absorbs the light emitted by sodium, lithium, calcium, strontium, and barium, and transmits that emitted by potassium, cæsium, and rubidium.

J. S. H.

The Horsepower of Pigeons. E. HUGUENARD, A. MAGNAN and A. PLANIOL. (*Comptes Rendus*, Nov. 19, 1923.)—Flying pigeons were made to unwind a thread wrapped around a reel. The number of revolutions were automatically recorded and on the same paper fifths of a second were marked off at the same time. From these two records the velocity of flight was determined. In addition a little Prony brake was brought into play by which the bird's pull on the thread was measured. The highest amount of work done in a second was 1.29 kilogrammeters and the least was .36. The work per second for one kilogram of the weight of pigeon ranged from 2.63 to .73 kilogrammeter. The largest of these quantities corresponds to a rate of 1/30 H.P. per kilogram. As the particular bird weighed about a pound, this would be a development of one H.P. for 30 pounds weight. There is, however, no reason to assume that the pigeons were doing their best either in speed or in traction. The authors remark that "the animal manifested a certain repugnance to flying under these conditions." G. F. S.

The Spectra of Sparks Formed in Liquids. MAURICE CURIE. (*Comptes Rendus*, Nov. 19, 1923.)—Sparks were made to pass through liquid bromine, melted sulphur and phosphorus and through liquid oxygen and nitrogen. In all cases a continuous spectrum was obtained. This negatives the suggestion that the presence of hydrogen in the liquid is necessary in order that a continuous spectrum be produced, for hydrogen is wanting in all the liquids used.

G. F. S.

New Extension of the Spark Spectra of Tin and Zinc in the Schumann Region. MESSRS. L. and E. BLOCH. (*Comptes Rendus*, Nov. 19, 1923.)—Improvements made on their previous methods extend the range of their spectrograph to 1300 Ångstroms. For the spark spectrum of tin they add forty-five lines to the number they previously reported, while seventy-three new lines for zinc are listed. G. F. S.

CORRESPONDENCE.

(A Note of Correction.)

The Editor of the
JOURNAL OF THE FRANKLIN INSTITUTE,
Philadelphia, Pennsylvania.

In our paper in the JOURNAL OF THE FRANKLIN INSTITUTE, of September, 1923, on "The Coloring and Thermophosphorescence Produced in Transparent Minerals and Gems by Radium Radiation," reference was made on page 380 to synthetic emerald. The reality of synthetic emerald having been questioned, we have made some inquiry with the following results:

The specimen referred to was a cut "stone" received through commercial channels under the designation synthetic emerald. We are informed that while this term is current, it is not accepted by the most ethical jewelry trade, and when used at all is understood to refer to an imitation in glass or in some more precious material. Determination of the density, hardness, and optical properties of the specimen in question has shown it to be such a glass imitation.

Reëxamination of our experimental material has been extended to all specimens about which there could be any question. The only additional correction that appears necessary refers to another specimen received under the designation smoky topaz. Its physical properties indicate it is smoky quartz which is quite commonly referred to as smoky topaz. Its coloration under radiation was entirely similar to that exhibited by other smoky quartz varieties.

We are indebted to Mr. G. W. Davis, of the Bureau of Mines, Professor J. C. Jones, of the University of Nevada, and Dr. W. T. Schaller, of the Geological Survey, for assistance in these identifications.

S. C. LIND and D. C. BARDWELL.

Bureau of Mines,
Washington, D. C.,
December 19, 1923.

The Thermal Conductivity of Liquids. P. W. BRIDGMAN. (*Proc. Nat. Acad. Sci.*, Oct., 1923.)—In this paper is given for the very first time determination of the rate at which the thermal conductivity of liquids varies with the pressure exerted upon them. The liquid examined was contained between two concentric cylinders. The heat was supplied along the axis of the inner cylinder, and flowed outward radially from one cylinder to the other through the liquid. The method is fitted for the measurement of small conductivities and for their measurement under different pressures. An accuracy of a fraction of a per cent. is claimed.

Fifteen liquids were investigated. For each, six results are given, the absolute conductivities at 30° and at 75° C., the pressure being one atmosphere; the ratios of the conductivity under 6000 kg. per square centimetre to that at atmospheric pressure, the temperature being 30° in both cases; the same ratio for 75°; and the two ratios, for 30° and 75°, respectively, of the conductivity at 12,000 kg. to that at one atmosphere. These are in general the results. "At atmospheric pressure the conductivity decreases with rising temperature, except for water. At constant temperature the conductivity increases with rising pressure, the increase not being linear with the pressure, but the increase in the first 6000 kg. is relatively greater than in the second. The total increase under 12,000 kg. varies from 1.5 to 2.7 fold, the increase being greater for the more compressible liquids. The proportional increase is greater at the higher temperature. Three of the liquids, acetone, toluol and water, at 30° were converted into solids by the highest pressure. Such solidification was not found at all at 75°."

The author then turns to the theory of thermal conductivity in liquids. He argues that the mechanism of conduction in liquids is not the same as in solids because in liquids the value of the conductivity is so much smaller. Again, there must exist a difference between the processes of conduction in liquids and in gases, since a relation connecting viscosity, specific heat and conductivity holds for gases but fails for liquids. In a simple manner he derives a formula for liquids by which the thermal conductivity can be calculated from a knowledge of the velocity of sound and the mean distance from the centre of one molecule to that of the next, the molecules being in cubical array. He applies this formula to those of the fifteen liquids for which the necessary data are known. The calculated conductivities at one atmosphere agree fairly well with the measured values. "It is interesting that the conductivity of water, which is three or four times as high as that of the ordinary organic liquid, is reproduced by the formula. The high conductivity of water appears, therefore, not to be due in any special way to the molecular peculiarities of water (two or more molecular species), but is directly referable to its low compressibility and the fact that the centres of the molecules in water are closer together than in the ordinary liquid. The formula gives the right sign for the temperature coefficient of conductivity at atmospheric pressure, both for ordinary liquids and water." It does not, however, account well for the effect of pressure on conductivity.

The contents of this paper are of high value both for the measurements presented and for the theory advanced. G. F. S.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

REDETERMINATION OF SECONDARY STANDARDS OF WAVE-LENGTHS FROM THE NEW INTERNATIONAL IRON ARC.[1]

By W. F. Meggars, C. C. Kiess and Kelvin Burns.

[ABSTRACT.]

THE system of secondary standards of wave-length now in common use was derived from an axial part about 2 mm. wide in the centre of an iron arc about 6 mm. long, and was established before the full importance of operating conditions of sources was recognized. In this type of arc, certain lines, grouped as *c* and *d* lines because of their sensitiveness to pressure, appeared to be displaced with respect to others grouped as *a* and *b* lines, so that the International Astronomical Union in 1922 recommended that the length of the arc be 12 to 15 mm. and that light be taken from a central zone not to exceed 1.5 mm. in width. These changes in the standard iron arc made it desirable to redetermine the secondary standards of wave-length. The well-known interferometer method of Fabry and Perot was employed to measure wave-lengths of selected lines in the iron spectrum directly in terms of the primary standard, the wave-length of the red radiation from cadmium which served for the wave-length-meter comparisons. New results are given for 159 lines between 3370 Å. and 6678 Å., including eighty-four of the international secondary standards. For twenty-three lines belonging to groups *c* and *d*, the secondary standards minus the new values average + 0.0072 Å. There is also a systematic difference for lines of groups *a* and *b*, forty-four such lines averaging 0.0029 Å. less than the present international values. The reason for the latter divergence is not obvious, but it may be due to a real error in the international system which, it is pointed out, was not established strictly according to the logical definitions of such a system nor with the accuracy which might be possible now in a redetermination.

* Communicated by the Director.

[1] Scientific Papers, No. 478, price five cents.

INTERFEROMETER MEASUREMENTS OF THE LONGER WAVES IN THE IRON ARC SPECTRUM.[1]

By W. F. Meggars and C. C. Kiess.

[ABSTRACT.]

THE international system of secondary standards established by interferometer comparisons of the wave-lengths of selected lines in the iron arc spectrum with the wave-length of the primary standard, the red radiation from cadmium extends, at present, from the ultra-violet to the red, but no extensive comparisons of these spectra existed for iron waves longer than 6750 Å. Using the international iron arc as a source of secondary standards and cadmium vapor lamps similar to those used in the wave-length-meter comparisons for the primary standard, new values have been obtained for 161 lines ranging in wave-length from 5534.525 Å. to 8824.238 Å. Seventy-five of these are longer than 6750 Å. The probable error of each value is of the order of 0.001 Å. In the region in which these determinations overlap the international standards there is a systematic deviation indicating that the accepted international scale is nearly one part in a million too large. Comparison of these values with the relative ones obtained in the same spectral interval by Burns shows good agreement if the latter are adjusted to the new scale of absolute values. A figure illustrating the dispersion of phase change at reflection in interferometer mirrors of silver and copper is given.

A DIRECTIVE TYPE OF RADIO BEACON AND ITS APPLICATION TO NAVIGATION.[2]

By F. H. Engel and F. W. Dunmore.

[ABSTRACT.]

THE problem of improving the safety of marine and aerial navigation in time of fog and poor visibility has always been an important one. Many aids to such navigation have been established, one of the latest and most effective of which has been the radio direction-finder installed on shipboard and used in conjunction with radio beacons installed on light vessels.

[1] Scientific Papers, No. 479, price five cents.
[2] Scientific Papers, No. 480, price five cents.

This paper describes another method of safeguarding marine and aerial navigation, and, although somewhat resticted in its applications, the simplicity of the method makes it of special value in many instances. It makes navigation between fixed points possible regardless of visibility conditions and without dependence on landmarks or the magnetic compass.

The method requires no apparatus other than an ordinary receiving set on the ship or airplane. The directive transmitting properties of coil antennas are used which serve as a particular type of radio beacon. A coil antenna is directional when used as a transmitting antenna, much as it is when used as a receiving antenna; that is, the familiar figure-of-eight characteristic is obtained. This property is made use of in the directive type of double-coil antenna beacon described.

Two transmitting coil antennas are arranged at an angle of 135° with respect to each other. These coil antennas are arranged to be connected alternately to a transmitting set by means of a special switch, which is thrown rapidly from one closed position to the other. Waves are thus intermittently propagated directively from each coil, the intensity of the emitted wave with respect to the plane of the coils varying in accordance with a figure-of-eight characteristic. Anywhere along the bisectors of the angles formed by the two coils a receiving set will receive signals of equal intensity from the two coils. At any point not on one of these bisectors, signals from one coil will be strong and those from the other coil weak, giving an inequality in the two signals which may be readily noticed, since one signal occurs directly after the other.

Experiments conducted at the Bureau of Standards are described in which two single-turn coil antennas are used crossed at an angle of 135°. These coils were 45.75 by 15.25 m. (150 by 50 feet) in size and were connected alternately to a 5-kw. quenched-spark transmitting set. A frequency of 300 kc. (1000 m.) was used. Receiving observations were made on the U. S. Lighthouse Tender *Maple* along a course which extended east and west at a point on the Potomac River about 56.4 km. (35 miles) south of Washington. At this point there was found to be a zone of equal signals about a mile wide, and in which no noticeable difference in intensity of the signals received from the two coils

could be noticed. Outside this sector, however, the two signals were noticeably unequal in intensity.

Interesting results were obtained as a result of tests conducted on an airplane. Recent tests with a short trailing wire and heavy weight have shown this method to be effective in enabling a pilot to guide his airplane into Dayton, Ohio, from a point 161 km. (100 miles) distant.

One of the great advantages of this system over methods employing a radio direction-finder on the airplane is that the effect of side drift may be immediately noticed and corrected for by heading the airplane at the correct angle into the wind so that the airplane remains in the equi-signal zone, thus enabling the pilot to maintain a straight course along the line of direction to the transmitting coil beacon.

A NEW ELECTRICAL TELEMETER.[1]

By Burton McCollum and O. S. Peters.

[ABSTRACT.]

DEVELOPMENT work has been in progress for several years at the Bureau of Standards on an electrical telemetric device suitable for the measurement of strains, forces, displacements, and accelerations, with the view of making an instrument remote reading and remote recording, and at the same time adapted to the measurement of quantities that are rapidly varying in value. Instruments capable of accomplishing these purposes would have numerous advantages over those for similar purposes now in use, since the latter are suitable only for measuring values that are relatively steady, and instead of being remote reading or recording must be read at the point of measurement. Satisfactory progress has been made and instruments developed that have sufficient accuracy and stability for many kinds of engineering measurements.

For their operation these new instruments depend upon the pressure-resistance characteristic or the corresponding displacement-resistance characteristic of a stack of carbon plates. Previous attempts to make use of these characteristics in making engineering measurements have met with little success on account of erratic changes of resistance in the stacks, hysteresis effects,

[1] Technologic Papers, No. 247, price fifteen cents.

and inability to obtain a linear relationship between resistance and pressure or displacement. The first of these has been overcome by maintaining the stack always under considerable pressure and confining changes of pressure and displacement within comparatively narrow limits to prevent any lateral shifting of the carbon contacts. Care is also taken to apply pressure changes axially to the stack to prevent bending or twisting.

Hysteresis effects have been made negligible by the use of a mounting without mechanical joints, so that if a given pressure or displacement is approached from either a higher or lower value the result is practically the same, whereas with mechanically jointed mounting frames there is a wide discrepancy, in some cases amounting to as much as 50 per cent.

A linear characteristic is obtained by incorporating in each instrument two stacks of plates in such a way that the force or displacement under measurement causes the resistance of one stack to increase and the other to decrease. By experiment it has been found that the cumulative changes of resistance of the pair of stacks gives substantially a straight line characteristic to the instrument.

In order to utilize the change of resistance of the stacks they are made two of the arms of a Wheatstone bridge, with fixed resistances as the other two arms. The bridging instrument may be a milliammeter, galvanometer, or oscillogaph element, and the deflections may be read directly or recorded photographically.

Practical applications so far made consist of the following:

(1) Measurement of loads in airplane stay cables during flight.

(2) Measurement of strains in airship girders and bridge members during construction tests.

(3) Tests of bridge members subjected to live loading.

(4) Tests of airship girders and bridge members in the laboratory.

(5) Measurement of pull on pressure arm of a dynamometer.

(6) Measurement of pressures ranging from a few millimetres of mercury to 40,000 lbs./in.^{2}

The use of these instruments results not only in a great saving of time and effort where a great many readings are to be made, but also enables the making of several classes of measurements not hitherto obtainable in their true proportions.

EXPOSURE TESTS ON COLORLESS WATERPROOFING MATERIALS.[1]

By D. W. Kessler.

[ABSTRACT.]

ABOUT three years ago a series of tests was started at the Bureau of Standards to determine the relative effectiveness and durability of several colorless waterproofing materials. Samples of the commercial materials were secured from the producers, and the non-proprietary processes were made up in the laboratory. The treatments were applied to specimens of sandstone and limestone, which were afterwards put out in the weather for a long period of exposure. At intervals of a month or so the specimens were brought into the laboratory and submitted to a thirty-minute absorption test. The amount of water absorbed was determined in the usual way, that is, by weighing the specimens before and after immersion.

The data obtained from numerous absorption tests during two years of weathering have been shown by curves, which indicate the effectiveness and rate of deterioration of the various treatments.

Another phase of the work was the determination of the effect of the treatments on the appearance of the surface to which they are applied. The greater portion of the treatments were found to produce some discoloration, which in many cases would be considered objectionable. After a few months of weathering this discoloration disappeared, and at the end of eighteen months the treated stone appeared cleaner than that which was not treated.

The waterproofing materials experimented with fall logically into five groups, *viz.*, first, petroleum distillates and fatty substances dissolved in mineral spirits; second, aluminum soap or a mixture of this with heavy petroleum distillates, fatty or resinous substances dissolved in mineral spirits, coal-tar naphtha or turpentine; third, resinous materials dissolved in coal-tar naphtha; fourth, water solutions of inorganic salts, glue, or soluble soaps; fifth, two aqueous solutions which are applied as individual treatments and react chemically with each other, precipitating an insoluble substance in the pores of the stone. A typical example of the first is paraffin or a mixture of paraffin and China wood oil

[1] Technologic Papers, No. 248, price fifteen cents.

dissolved in gasoline or similar solvent. The appearance of the solution may be nearly clear or slightly yellow to brown. The second group is of similar appearance, but some of the commercial compounds are less limpid and have a syrupy consistency. The third consists of light varnishes, and has the characteristic amber color. The fourth group consists of clear or milk-like solutions, some of which have a rancid odor. The principal example of the last group is known as Sylvester's process, which is non-proprietary.

It consists of a solution of alum, which is applied to the stone and followed by a solution of soft soap. The two solutions react and form an aluminum soap which is supposed to seal up the pores.

In addition to the materials described, two treatments were included which are widely different from any of the above. One consisted of paraffin applied in the molten condition to the stone which has been previously heated. A second heating is also made after the paraffin application, to obtain a more thorough penetration. The other treatment consists of a solution of cellulose nitrate in a solvent-like fusel oil. This material has a syrupy consistency and a strong odor resembling banana oil.

The treatments giving the highest waterproofing values and showing very little deterioration during the two years of exposure were those which employed paraffin alone or in conjunction with China wood oil as the waterproofing medium. The treatment which gave the highest waterproofing value on all textures was that which consists of paraffin applied in the molten condition.

UNITED STATES GOVERNMENT SPECIFICATION FOR VEGETABLE-TANNED LEATHER BELTING.[*]

THE United States Government specification for vegetable-tanned leather belting was adopted by the Federal Specifications Board on July 3, 1922, for the use of the departments and independent establishments of the Government in the purchase of materials covered by it. The specification covers the purchase of miscellaneous sizes of single and double-ply vegetable-tanned leather belting; also waterproof and waterproof-dressed belting. The usual requirements are included relative to bids,

[*] Circular No. 148, price five cents.

packing, marking, shipping and inspection. The quality of the leather to be used is covered by specifications as to hides, tannage, stuffing, stretching, finish, and location on the hide for cutting. The limitations of the construction of the belting are in accordance with the best commercial practice and include such items as length of strips, method of joining, selection, length and location of laps, cementing, widths and tolerances, and thickness requirements. Technical tests are provided as a measure of quality and include requirements for tensile strength, percentage elongation, cracking, piping, water absorption, waterproof cement, stuffing, ash, acid, and glucose contents. The method of sampling is specified and complete instructions are given for conducting the technical tests.

A New Historic Map of the United States.—"Know America First" is a popular slogan, and a government publication is just announced which has value in the application of it. This is entitled "Boundaries, Areas, Geographic Centres, and Altitudes of the United States and of the Several States, with a Brief Record of Important Changes in their Territory," by E. M. Douglas, and has been issued by the Department of the Interior as Bulletin 689 of the Geological Survey. The report is sold by the Superintendent of Documents, Washington, D. C., at nominal cost. It gives numerous little-known facts relating to the organization of the original thirteen colonies and of the states after the Revolution.

California has within its boundaries the highest and the lowest points of dry land in the United States proper, and Alaska has the highest mountain peak in the possession of the United States. Colorado is the state having the greatest average altitude; Delaware has the least.

The bulletin contains a facsimile reproduction of a map of the British and French possessions in America as they were known in 1755. A copy of that map was used in the preparation of the treaty with Great Britain in 1782, when the United States was first recognized as an independent nation. The book also contains numerous other maps illustrating the growth of the United States and the changes in its boundaries from early colonial days up to the present time.

The statement in the official announcement above that the United States was recognized as an independent nation by the treaty of 1782 is not quite accurate. That treaty recognized the thirteen states by name as independent sovereignties. The term "United States" had been officially adopted by the Continental Congress in August, 1776, as a designation, but state sovereignty was the dominant note for many years thereafter. H. L.

NOTES FROM THE RESEARCH LABORATORY, EASTMAN KODAK COMPANY.*

ON THE RELATION BETWEEN TIME AND INTENSITY IN PHOTOGRAPHIC EXPOSURES.[1]

By L. A. Jones and E. Huse.

THE effect of the reciprocal variation of time and intensity in photographic exposures was exhaustively studied on Seed 23 and 30 plates and on motion picture positive film. Exposures were made to white light, using incandescent electric lamps of various candle-power, each lamp being operated at a color temperature of 2500° K. The total intensity range of exposure was of the order of 1 : 500,000. Laboratory pyro was the developing agent used in this work. The instrument used for exposure is described by one of the authors in the *J. Opt. Soc. Amer.*, 7, 305 (1923). A summary of the results obtained is presented. (1) An examination of the final density-log intensity curves of each of the three materials shows a distinct departure from a straight line, indicating a failure of the reciprocity law, $E = It$. (2) Seed 23 shows the least departure from a straight line, while cine positive film shows a marked failure of the reciprocity law in the low intensity region. (3) Tests made relative to the variation of gamma with intensity when the curves were plotted on a time scale were negative in the case of Seed 23 and Seed 30 plates. Cine positive film showed a decided decrease in gamma at low intensities in the neighborhood of 0.022 meter-candle and less. (4) Schwarzschild expressed the failure of the reciprocity law by the following equation, $E = It^p$. From the data obtained in this investigation the value of p was computed. The following table is self-explanatory, p being computed according to the following formula:

$$p = \frac{(\log I_1 - \log I_2)}{(\log E_2 - \log E_1) + (\log I_1 - \log I_2)}.$$

In order to show in a different way the magnitude of the failure of the reciprocity law, values of sensitivity (relative speed) have been computed and tabulated. It will be seen that the

* Communicated by the Djrector.

[1] Communication No. 193 from the Research Laboratory of the Eastman Kodak Company and published in *J. Opt. Soc. Amer.*, Dec., 1923, p. 1115.

Log *I*.	Seed 23.		Seed 30.		Cine Positive.	
	p	*S*	*p*	*S*	*p*	*S*
2.1	...	74	...	89	...	100
1.8	1.15	80	1.07	93	1.00	100
1.5	1.11	87	1.03	96	1.00	100
1.2	1.15	93	1.00	96	1.00	100
0.9	1.00	96	1.03	98	1.00	100
0.6	1.00	96	1.00	98	.97	98
0.3	1.03	98	1.03	100	.97	95
0.0	1.03	100	1.00	100	.88	87
$\bar{1}$.7	1.00	100	.97	98	.86	78
$\bar{1}$.4	.97	98	1.00	98	.83	68
$\bar{1}$.1	1.00	98	.97	96	.81	57
$\bar{2}$.8	.97	96	.94	91	.77	47
$\bar{2}$.5	1.00	96	.91	85	.77	37
$\bar{2}$.2	.94	91	.88	78	.79	32
$\bar{3}$.9	.94	87	.86	69	.72	24
$\bar{3}$.6	.91	80	.86	62	.62	17
$\bar{3}$.3	.91	76	.83	54	..	..
$\bar{3}$.0	.91	71	.81	44	..	..
$\bar{4}$.7	.88	61	.79	38	..	..
$\bar{4}$.4	..	..	.63	32	..	..

Schwarzschild exponent p is not constant. Many questions relative to this question are not answered in this paper, but further work is in progress.

THE EFFECT OF ELECTROLYSIS ON THE RATE OF CORROSION OF METALS IN PHOTOGRAPHIC SOLUTIONS.[1]

By J. I. Crabtree, H. A. Hartt, and G. E. Matthews.

THE resistivity of a metal or alloy towards any photographic solution is impaired if it is in electrical contact with a second metal, which is more electro-positive in the solution used. A photographic electromotive series is given wherein the rate of corrosion of the metal or alloy is roughly proportional to the distance of separation of the metals as listed. The metals plated with silver, either chemically from an exhausted fixing bath or by electro-plating, are more resistant to developing solutions than unplated metals according to the homogeneity of the silver

[1] Communication No. 191 from the Research Laboratory of the Eastman Kodak Company and published in *Ind. Eng. Chem.*, Jan., 1923, p. 13.

coating, but their resistivity towards fixing solutions is only slightly greater than that of the unplated metals. The presence of copper or its alloys in electrical connection with a more electropositive metal in a photographic developer materially shortens the life of the developer. Tin and alloys containing tin tend to produce high initial fog in a photographic developer, but this fog later decreases to a normal value when the solution possesses better developing powers than a blank, indicating the possibility of using a tin alloy or a metallic couple which will gradually discharge tin into the developer, thereby acting as a preservative of the solution. For the practical worker, the suitability of various metallic couples for use with developing and fixing solutions is discussed.

Ernest Solvay's Views of the Relations between Energy and Mass. H. A. LORENTZ and E. HERZEN. (*Comptes Rendus,* Nov. 12, 1923.)—"The great industrialist, Ernest Solvay, was not, properly speaking, a physicist and, moreover, had taken the courses of no university, but he had a sincere enthusiasm for pure science, and gladly devoted himself to reflections on the nature of the universe, when his business left him the requisite leisure. Of a very independent mind he was unwilling to constrain himself to follow classical methods, and thus to set a limit to what he might achieve. By the plan he adopted he kept all his originality and thereby sometimes arrived at interesting conceptions which lay quite outside of the orthodox science of the time and which had to wait until a later time for recognition." One such conception arrived at was the very modern belief in the interchangeability of matter and energy. Under date of July 6, 1896, he deposited a sealed communication with the Belgian Academy of Sciences, in which he says, "It is not merely to-day that I have gained the conviction that matter is transformable into energy and *vice versa*. In order to be able to give to this opinion the certainty of a fact I have set myself to work. When for the first time I fixed my mind on the problem of the constitution of bodies, matter and energy appeared to me as elements of the same fundamental nature, everywhere coexistent and interchangeable. The quantitative increase of one of them in any point whatever of space occasions necessarily the diminution of the other at some other place. One of these elements is, so to speak, only a form, a modality or, more correctly, a transformation of the other. My ideas on this subject go back to 1858. At about that time I was suddenly struck one day by the thought, which assumed an extraordinary force in my mind, that heat (we say since then, energy) can have only a material origin. When we heat a body, when we make it notably change its state, the heat that ceases to be perceived as such, the heat that becomes latent (we say at the present time, that is changed

into internal work) is converted into matter and is added to the matter already in the body. From the moment when I ceased to consider matter as permanent and came to regard as possible the transformation of matter into energy and *vice versa* I formed the purpose of demonstrating the fact by experiment." In 1878 he presented his views to the chemist, Stas, who opposed them with vigor. This did not deter him from undertaking a series of experiments from 1879 to 1881. He sought for a change of mass when considerable quantities of solid chemicals reacted and, again, when mechanical energy was expended upon matter. He had a gyroscope constructed that made 600 to 800 revolutions per second and weighed it carefully at rest and in rotation. In no case was a change of mass observable. "This lack of success," he writes, "was unable to discourage me. Upon reflecting on it the experiments made prove once more that the material equivalent of heat was not to be detected under the conditions of the experiment and nothing more than this was proved. Furthermore considerations of different kinds led to my thinking that this equivalent must to be so small that reasoning alone supported by computation could determine it, if, indeed, it can be determined at all."

The authors comment thus on Solvay's opinions, "We know to-day that he was right. Mass is no longer considered as an independent and unalterable attribute of matter, but as intimately connected with energy, increasing and decreasing with it. We cannot augment the speed of a moving body, nor raise its temperature without communicating energy to it, that is, without increasing its mass, but the coefficient by which the transfer is affected from a quantity of energy in mechanical units to the corresponding mass is the reciprocal of the square of the velocity of light. In the c.g.s. system it is unity divided by 9 followed by 20 ciphers. This is the tiny coefficient predicted by Solvay." Small wonder he could not measure or even detect it. G. F. S.

Thermal Conductivities of Some Metals in the Solid and Liquid States. W. B. BROWN. (*Phys. Rev.*, Aug., 1923.)—The flow of heat was from the top to the bottom of a cylinder of the metal. A guard ring simplified the problem of the loss of heat. Tin, cadmium and thallium were investigated. The thermal conductivities of both tin and cadmium grow less as the melting point is approached, then there is a very marked decrease. "The conductivities of tin and cadmium decrease at the melting point by over one-third and one-half, respectively." In the cases of both metals the conductivity of the molten liquid at first diminishes and then increases as temperature rises. Before thallium melts its conductivity shows a sharp drop at about 120°. The conductivity in both states of several eutectic alloys was measured. In all the effect of melting was to lower the conductivity. In the molten state all showed a rather rapid rise of conductivity with temperature. G. F. S.

NOTES FROM THE U. S. BUREAU OF CHEMISTRY.*

A CHEMICAL AND STRUCTURAL STUDY OF MESQUITE, CAROB, AND HONEY LOCUST BEANS.[1]

By G. P. Walton.

[ABSTRACT.]

GREAT quantities of mesquite beans are allowed to go to waste each year in the United States. In an effort to promote their utilization, the Bureau of Chemistry undertook an investigation to determine whether or not these beans might be made to serve some useful purpose.

The literature was searched for data on the nutritive value of the mesquite fruit. Samples were analyzed in the laboratory to determine the content of sugar and other crude nutrients, and a process for separating the mesquite bean into its component parts (high-protein seed kernel, seed coat, and sugary pod) was devised. The results of this work, supplemented by notes on carob and honey locust beans, are given in Department Bulletin 1194.

PROTEINS OF WHEAT BRAN.

I. ISOLATION AND ELEMENTARY ANALYSES OF A GLOBULIN, ALBUMIN, AND PROLAMINE.[2]

By D. Breese Jones and C. E. F. Gersdorff.

[ABSTRACT.]

THREE proteins, an albumin, a globulin, and an alcohol-soluble protein, have been isolated from wheat bran. The bran, which originally was exceptionally clean, was rapidly washed in cold water and immediately dried at a low temperature. In this way the greater part of the adhering particles of other portions of the wheat kernel was removed. The bran was then ground to a fine powder. This contained 17.25 per cent. of protein ($N \times 6.25$). By excessive exhaustive extractions with distilled water, 4 per cent. sodium chloride solution, 70 per cent. alcohol, and 0.5 per cent. sodium hydroxide solution, 86.61 per cent. of the total

* Communicated by the Chief of the Bureau.

[1] Issued as Dept. Agr. Bul. 1194, Dec. 22, 1923.

[2] Published in *J. Biol. Chem.*, **55** (Nov., 1923) : 117.

protein in the bran was extracted (N × 6.25). The percentages of proteins actually isolated, expressed in terms of the total protein in the bran, were as follows: Albumin, 16.64; globulin, 13.62; alcohol-soluble protein, 31.01. Analyses showed these proteins to have the following average elementary percentage composition: Albumin, N 15.42, C 53.21, H 6.71, S 1.35; globulin, N 17.76, C 53.43, H 7.40, S 0.91; alcohol-soluble protein, N 15.35, C 54.25, H 6.75, S 1.35.

THE VALUE OF SWEET POTATO FLOUR IN BREAD-MAKING.[3]

By H. C. Gore.

[ABSTRACT.]

A LARGE number of experiments in which a series of mixtures of varying percentages of sweet potato flour and hard wheat flour have been conducted in the Bureau of Chemistry. The use of sweet potato flour increased the volume substantially. One and one-half per cent. of sweet potato flour seemed to give the best results.

Experiments on the Sign of the Electric Charge Assumed by a Metal Immersed in a Liquid. W. D. KLEEMAN and W. FREDERICKSON. (*Phys. Rev.*, Aug., 1923.)—Very thin wires of different substances were suspended at the lower ends of silk threads two metres long. About 3 centimetres of the length of the wire was in the liquid contained in a tank 3 × 4 × 6 cm. A direct current was passed from one aluminum electrode to the other, the wire having its length roughly perpendicular to the stream lines. Usually upon the passage of the current the wire moved either with or against the current. The distance through which the lower end was displaced equalled in general several times the diameter of the wire. Reversing the direction of the current caused the motion of the wire to reverse in direction. Wires of the following in distilled water moved against the current and hence assumed a negative charge—C, Ag, Al, Au, Cu, Mg, Mo, Ni, Pt, Sn, W, Zn, while Bi, Cd, Fe, Pd received a positive charge. "The metals Ag, Au, Bi, Fe, Pd, and Pt have been obtained in colloidal solution in water, and the directions of their motion under the action of an electric field have been observed. The results indicate that the metals Bi, Fe and Pb are positively charged with respect to water, and the metals Ag, Au and Pt are negatively charged. This falls into line with the preceding results."

G. F. S.

[3] Published in *Ind. Eng. Chem.*, 15 (Dec., 1923): 1238.

NOTES FROM THE U. S. BUREAU OF MINES.*

THE PARAFFIN PROBLEM IN OIL WELLS.

By R. Van A. Mills.

THE Bureau of Mines has made a preliminary study of the so-called "paraffining" of oil wells and methods of preventing and remedying that trouble. The increased difficulties in operation and the losses of production caused by the deposition of gummy and waxy hydrocarbons, commonly called paraffin, in the wells, tubing, other pumping equipment, and in the pores of the productive sands, have long been recognized but the trouble has not been overcome. The nature and causes of the trouble, together with some of the possible methods by which it may be diminished or overcome, are outlined in Serial 2550, recently issued by the bureau.

Present methods for preventing and removing paraffin are not all that is to be desired. The cost of cleaning out paraffin is high and the results seem to be only temporarily beneficial. Wells that have increased their rates of production several hundred per cent. upon being cleaned, often go back to their old rates of production within three or four weeks after they are cleaned. The problem then is not only to clean the wells beneficially and economically, but to maintain the beneficial effects long enough to make the operation profitable. The redeposition of the paraffin and associated substances, especially calcium carbonate, must be retarded or prevented. The problem is one worthy of considerable investigation, and is one which the Bureau of Mines hopes to attack further in the near future.

GASEOUS CONTENT OF GROUND WATERS AS AN AID TO THE OIL AND GAS PROSPECTOR.

By G. W. Jones, W. P. Yant, snd E. P. Buxton.

DATA obtained in recent research work by the Bureau of Mines show that the analysis of the gases dissolved in underground waters may be used by the prospector or geologist as an

* Communicated by the Director.

additional aid in discovering new oil or gas fields. The hydrocarbons present in the water serve to indicate whether oil or gas sands exist in the region through which the waters have passed. A portable field apparatus has been developed by the bureau which can be used for removing and analyzing the gases dissolved in the waters. Analyses were made on waters from various localities, and the significance of these waters determined, with reference to the detection of oil and gas.

If water of underground origin traverses a gas or oil sand it will absorb a definite quantity of hydrocarbon vapors, and will carry these vapors to the surface when tapped by a well. When the water is exposed to the air at the surface, the gases and vapors will be given off and their place taken by oxygen and nitrogen from the air. Therefore, an analysis of the gases in waters reaching the surface from an underground source is of value in determining whether these waters have traversed or came in contact with hydrocarbon-bearing strata. With the apparatus mentioned, it is possible to determine whether the vapors are mainly of natural gas composition—methane (CH_4) and ethane (C_2H_6)—or are composed mostly of heavier petroleum vapors—ethane, propane (C_3H_8), and butane (C_4H_{10}).

The writers realize from the tests which have been made that the application of water analysis will be of little value for certain regions—for example, in the Pennsylvania fields where there are many producing sands. Samples of water of deep origin from this region nearly always show on analysis high percentages of hydrocarbon vapors due to the many gas and oil sands present. For newly prospected regions, analyses of the gases in the underground waters should be decidedly helpful provided that the source of the water is known, and means are available for obtaining waters of deep origin. This suggests the value of testing the water in a well as drilling progresses, and as an aid in determining whether it is advisable to drill deeper in quest of oil or gas sands. The geologist should thus be aided in his predictions as to what newly prospected regions are most likely to be productive of petroleum or natural gas. Further details are given in Serial 2553, recently published.

FERRIC SULPHATE AND SULPHURIC ACID FROM SULPHUR DIOXIDE AND AIR.

By Edmund S. Lever and R. V. Thurston.

DURING the development of the sulphur dioxide leaching process for the treatment of "mixed" copper ores at the Southwest experiment station of the Bureau of Mines, the pulp from treatment of roasted cupriferrous pyrite with sulphur dioxide gases and water showed an unexpected amount of sulphuric acid. It was found that this was due to iron in the solution, and also that this iron tended to oxidize to the ferric state if the concentration of sulphur dioxide in the roaster gases used did not rise above a certain figure. While the percentage of iron present was small, it was enough to cause an entirely different set of conditions from those of the original sulphur dioxide leaching process and to promise a much wider application of the general idea. Sulphurous acid dissolves only certain copper minerals, sulphuric acid solutions certain additional minerals, and ferric sulphate solutions certain further additional copper minerals, so this observation was of importance in connection with possibilities in the hydrometallurgy of the so-called "mixed" or partly oxidized copper ores.

A study of the reactions involved has been carried on by various chemists of the bureau, chiefly by L. R. Eckman, L. E. Roberts, W. D. Bonner, C. G. Maier, and the writers.

Oxidation of ferrous sulphate solutions by blowing with air is exceedingly slow, and has never proven to be of practical value, likewise the oxidation of solutions of sulphur dioxide by air. However, the oxidation of mixed solutions of sulphur dioxide and ferrous sulphate by air is quite rapid and the reaction promises to be of commercial value. The actual chemical reactions are somewhat complicated and not definitely known, but the following will tend to show the beginning and final products:

$$(1)\quad 2FeSO_4 + SO_2 + O_2 = Fe_2(SO_4)_3$$

$$(2)\quad H_2O + SO_2 + \tfrac{1}{2}O_2 = H_2SO_4$$

These two reactions take place simultaneously or in the order given, depending on conditions. As a rule, when bubbling a mixture of air and sulphur dioxide through a solution containing ferrous sulphate, or when bubbling air through a solution containing both ferrous sulphate and sulphur dioxide, the iron is

oxidized first, all the sulphur dioxide being used to make the extra SO_4 of the ferric sulphate and only after most of the iron is oxidized does the acidity of the solution begin to rise. Solutions containing ferrous sulphate up to saturation can be oxidized in this way and the acidity can be carried easily to 5 per cent. and even to 10 per cent. or higher. For many purposes these ranges of concentration are sufficient, especially for copper leaching.

It is probable that solutions prepared by the above reactions will be utilizable for the treatment of all oxidized copper minerals, and in addition for the recovery of copper from concentrator tailing where the copper is present both in oxidized minerals and in sulphides or native state which can be attacked by the ferric sulphate.

The Bureau of Mines has developed apparatus and a process that have been tried out experimentally on a number of ores with encouraging results. Further details are given in Serial 2556.

On the Relative Velocity of Blue and Yellow Light. HARLOW SHAPLEY. (*Proc. Nat. Acad. Sci.*, Nov., 1923.)—" For the accurate measurement of the relative velocity of light of different wave-lengths there are three principal requisites—a source that emits vari-colored light signals at controlled or predictable intervals, a fairly accurately measured base line of great extent, and a device for recording the signals sent over this base line in light of different colors." The source used was the variable globular cluster Messier 5. Its distance from the earth is approximately 40,000 light years. The signalling apparatus was the change of brightness. The times of maximum brightness can be accurately predicted. The cluster was photographed with the 60-inch reflector on Mount Wilson in both blue and yellow light. It was found that in both colors of light the times of reaching median magnitude were practically identical. This could not well be true if one length of wave outran the other. It thus appears " that the velocities of blue and yellow light through interstellar space differ by one part in twenty thousand million. The test is differential and is quite independent of the actual velocity of light, which is yet affected by errors probably as great as one part in twenty thousand."

It will be recalled that some years ago a part of the Boyden Premium was awarded to Dr. Paul R. Heyl, who reached the same conclusion as that given above as a result of his study of the variable star, Algol. G. F. S.

THE FRANKLIN INSTITUTE.

(Proceedings of the Annual Meeting held Wednesday, January 16, 1924.)

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, January 16, 1924.

DR. WALTON CLARK, President, *in the Chair.*

The Board of Managers submitted its report. The report recorded the election to membership of the following Resident Members:

Cyrus N. Anderson, Esq.,
Patent Attorney,
Philadelphia, Pennsylvania.

Dr. Elbert C. Lathrop,
Vice-president and Treasurer,
Samuel P. Sadtler and Sons, Inc.,
Philadelphia, Pennsylvania.

Alexander Wilson, 3rd,
Special Assistant to Chief Engineer,
Philadelphia Electric Company,
Philadelphia, Pennsylvania.

the following Non-resident Member:

Dr. J. H. Mathews,
Professor of Chemistry,
University of Wisconsin,
Madison, Wisconsin.

and the following Associate Member:

Carrol Barnard Neblette, Esq.,
Associate Editor,
The Photographic Journal of America,
Philadelphia, Pennsylvania.

and additions to the Library by gift, 29 volumes and 21 pamphlets; by purchase, 42 volumes.

The report of the Board of Managers embodied the following resolutions, which were unanimously adopted by the Board at the Stated Meeting held on Wednesday, January 9, 1924:

Resolved, That the Board of Managers of The Franklin Institute recommend to the Institute the election to Honorary Membership of Dr. Edward Weston, President of the Weston Electrical Instrument Company, Newark, New Jersey, who on the second day of January was awarded the Institute's Franklin Medal in recognition of discoveries and inventions in the field of electricity, fundamentally contributing to the electric art, and

Resolved Further, That the Board of Managers of The Franklin Institute recommend to the Institute the election to Honorary Membership of Sir Ernest Rutherford, Cavendish Professor of Experimental Physics,

The University of Cambridge, Cambridge, England, who on the second day of January was awarded the Institute's Franklin Medal in recognition of successful researches, signally contributing to the present state of knowledge of the elements, their constitution and relationships.

On motion of Dr. Gellert Alleman, duly seconded, Dr. Edward Weston and Sir Ernest Rutherford were unanimously elected to Honorary Membership.

At the request of the Chairman the Secretary to the Board of Managers read the following Annual Report for the fiscal year ending September 30, 1923, which report had been prepared by the President:

To the members of
The Franklin Institute:

Your Board of Managers has instructed me to report to you upon the affairs of the Institute for the Institute year ending September 30, 1923, as below.

As is the usual practice, the Board's report quotes briefly from the reports of the Committees of the Institute and of its Board of Managers, with such comment as seems useful.

The Committee on Museum (Mr. Outerbridge, Jr., Chairman) reports the addition to our Museum of several important models. The statements of most interest to us in this report inform us that the rooms on the third floor of the Institute building, formerly used by the Committee on Instruction for the evening classes of the Institute, have been so altered as to make them suitable for exhibition purposes, and that most of our large collection of models and historical apparatus has now been transferred to these rooms. These exhibits are now so arranged in groups that one may conveniently examine and compare them. This arrangement makes a marked improvement in our Museum facilities and renders our very interesting and valuable collection much more accessible than heretofore. Any member of the Institute, student or other, would be much interested in these exhibits as now displayed.

The Committee on Publications (Doctor Rosengarten, Chairman) reports the completion of the 196th volume of the JOURNAL and of the 12th volume of the Year Book. The Committee reports the sale during the year of 124 copies of Dr. W. J. Humphreys' work on the "Physics of the Air." In all 1417 copies of this work have been sold. The great success which the Institute has had in the publication of this remarkable work of Doctor Humphreys has encouraged us to regard it as a precedent to be followed, and the Committee is now publishing Sir J. J. Thomson's lectures on "The Electron in Chemistry" in book form. Three thousand volumes are in course of preparation.

The report of the Committee on Sectional Arrangements (Doctor Keller, Chairman) is more comprehensive than usual, giving interesting summaries of the several important lectures delivered during the year under the auspices of the Committee.

Also the report of the Committee on Meetings (Doctor Alleman, Chairman) contains brief summaries of the lectures arranged by the Committee, which summaries are the more important matters covered in the report.

The Committee on Instruction (Mr. Paul, Chairman) reports a large decrease in registration of students and records the final decision to suspend

the school work. As evidencing the view that the school could be discontinued without injury to the cause of technical education, the Committee states that "The well-equipped and widely distributed Free Evening High Schools and other institutions of learning in the city are well meeting the demands of the community for instruction in the Mechanic Arts." The Committee is considering the practicability of adopting means of imparting to ambitious youths an advanced knowledge in the Mechanic Arts other than the night schools, which the Institute has maintained for ninety-nine years and now finds no longer important.

The Committee on Science and the Arts (Mr. Fulweiler, Chairman) reports seventeen cases disposed of during the year and twelve awards made. The report gives interesting detail of the ceremonies attending the award of The Franklin Medal to General Ferrié, of the French Army, and to Dr. A. A. Michelson, of the University of Chicago.

The report of the Committee on Election and Resignation of Members (Mr. Lesley, Chairman) records for the year a net decrease of ten in our membership. It is about our usual experience. Each year death takes from our membership; each year some members finding our work not useful to people in their particular lines of endeavor, and not having an interest in the discussion of abstract science, decide—doubtless wisely—that the price of their membership would be more usefully productive to them if otherwise expended, and act upon the decision. But except for the associates who leave us because death summons, the loss in members takes those of least interest in our work and to our work. Thus the character of our membership from the viewpoint of scientific interest is not materially—certainly not deleteriously—affected.

We learn from the report of the Committee on Endowment (Mr. Clamer, Chairman) that all recently pending transactions in connection with the settlement of the Bartol bequest have been concluded, except that the bequest has not yet been transferred to the Board of Trustees. The report contains a statement of the value of the Bartol bequest at the time of Mr. Bartol's death, the various settlements made with the widow and the two daughters, and of the value of the estate and bequest when received by The Franklin Institute. The Committee on Endowment had practically no activities during the year except in connection with the Bartol bequest, as no gifts of money or securities were received by the Institute in the twelve months.

The Committee on Library (Mr. Hall, Chairman) reports additions to the library of 4358 bound volumes, 214 unbound volumes, 1202 pamphlets, 7 photographs and 3 drawings, a total of 5784 items. This is an unusually large year's addition to the library. The Committee had at its disposal for the purchase and binding of books, pamphlets, etc., $5837. This fund is inadequate for the useful work which the Library Committee might accomplish in the purchase and binding of books, and we see no immediate prospect of being able to increase it. As in previous reports, we have to record the fact that while our library attendance is much smaller than it would be if the library were housed in a building more centrally located, it is to be noted that a large proportion of the people who come to the library come to consult many books and often spend days in such consultation. There is no doubt that our library

continues to be of great service to seekers after information in the Mechanic Arts.

The Managers in their report for the year 1922 told you of plans for the erection and equipment of a laboratory building to be used in part by the Institute in its Science and Arts Committee work and in part by the Bartol Research Foundation. The high cost of construction in 1923 decided the management not to erect a new laboratory building but to so alter three of the residences owned by the Institute on Nineteenth Street as to make them suitable for research laboratory work. The reconstruction of these buildings is about completed and we learn from men who are expert in such matters that we have in them a research laboratory entirely adequate to meet the needs of the Institute and of the Bartol Foundation. The reconstruction of these buildings and the equipment fitting them for laboratory work is costing approximately $100,000. We congratulate ourselves on the conservation of the funds of the Institute and of the Bartol Foundation through the determination to equip these buildings rather than build a new laboratory. The result is a maintenance of our expected standards of efficiency with a saving of several hundred thousand dollars in construction costs. This large sum will now remain in capital account and continue to earn interest applicable to the work of the Institute and of the Foundation.

The Laboratory Building as now about ready for occupancy contains an office for the Science and Arts Committee, which will be transferred from the Seventh Street Building; a small lecture room; an operative museum; a machine shop; a battery room; a room for the power equipment; a boiler room; twelve research laboratories; an office for the Directors; and living rooms for the Director and Mr. Parrish.

Lybrand, Ross Bros. and Montgomery, certified public accountants, have submitted to the Institute a detailed report covering all the financial transactions in connection with the administration of the Bartol estate for the period from the death of Mr. Bartol, December 19, 1918, to the transfer of the residuary estate to the Institute on March 26, 1923. Immediately after submitting this report, Lybrand, Ross Bros. and Montgomery opened books of account for the Bartol Foundation. The accounts of the Foundation are being kept separately from the accounts of the Institute.

Certain changes in the organization of the Foundation Committee were made necessary by the resignation of the position of Chairman by Mr. Charles Day. Mr. C. C. Tutwiler resigned as Treasurer. The Committee then elected Mr. Tutwiler, Chairman, Mr. Day, Vice-chairman, and Mr. Marshall S. Morgan, Treasurer.

The report of the Committee on Stocks and Finance (Mr. Forstall, Chairman), always of great interest, is of particular importance and interest this year and the Board of Managers ask your careful attention to it. This Committee report has not to do with the Bartol Foundation finances.

The Institute's operations of the year ending September 30, 1923, the period covered by the report, resulted in a so-called apparent deficit of approximately $10,000. This deficit has been covered by bank loans. As of September 30, 1923, the Institute owed the bank $10,000; otherwise we were free

from debt except for current bills and as between departments. The debt as between departments has since been settled. The budget for the year ending September 30, 1924, shows an expected outgo of $66,675. To offset this expected outgo there is an estimated income from dues, initiation fees, interest on funds held by the Trustees, and receipts from publications, of $47,280. This gives an apparent deficit of $19,395 for the operations of the year ending September 30, 1924.

It has been our custom in making up our financial statements not to include as income any gifts or bequests made to the Institute. We have excluded from our statements of income even bequests made without condition as to time, manner or direction of use. In recent years there have been several entirely unconditioned large gifts and bequests to the Institute available for use in the conduct of our work at the discretion of the Board of Managers.

In the last twelve years the Institute has received $378,000 of such unconditioned gifts and bequests. The funds making up this amount have been given into the custody of the Board of Trustees. These funds are regarded by the Managers and by our legal advisers as available for operating expenses. During the twelve years the apparent deficit—that is, the deficit resulting from our operations if we do not include in our estimate of income the unconditioned bequests of $378,000 as above—amounted to $48,000. The actual surplus—the excess of available income over expenditures—from the twelve years' operations is the difference between the $378,000 of entirely unconditioned funds received and the apparent deficit of $48,000, and equals $330,000.

It appears, therefore, that the activities of the Institute have been carried on so much within our actual income that in the past twelve years we have accumulated securities and other property applicable to the cancellation of old debts and of future deficits, having a value of $330,000. Of the $378,000 of unrestricted funds received during the past twelve years, the Trustees have set over to the Managers and the Managers have used in the payment of old debts and current operating expenses, $78,000, leaving in the custody of the Trustees of this unrestricted fund at this date $300,000. The figures we have been considering are book values. Some of the securities have depreciated and they and the other property held may not now have a selling value of more than $250,000. This surplus, having a selling value of about $250,000, is—as the Managers believe and are advised—available for meeting the operating expenses of the Institute.

The Trustees now express doubt of the wisdom of setting over to the Managers from these unconditioned funds in their custody the sum necessary to cover the estimated apparent deficit for the year ending September 30, 1924. A committee of the Board of Managers has been appointed to discuss this question with the Trustees and it is believed that the matter will be satisfactorily arranged during the present fiscal year.

With $250,000 market value of securities and property available—as we believe and are competently advised—to meet operating expenses and with other large sums so left by their deceased legators that in the course of nature they must soon come to us, we cannot regard our financial condition as otherwise than sound, though we are recording against ourselves apparent deficits likely by the end of this year to reach an accumulated amount of $30,000.

This condition while temporarily satisfactory as insuring for many years the maintenance of our credit as against anything but mismanagement, must be regarded as but temporarily satisfactory. To the end that our financial status may be made secure for an indefinite period, we must have more endowment. The Institute with its high prestige—the fruit of its good work—should be able to secure from its friends and beneficiaries such added endowment as will make its annual income balance its annual budgets without encroachment upon its invested principal. Remembering that the Institute's great and beneficial influence on physical science in America is broadly recognized and highly esteemed, it seems a task of no great difficulty to raise such an amount as is required for the protection of our credit with our present range of activities.

But the Managers have ambitions for the Institute and its work far beyond the present range of its activities. In our report of two years ago we told you at some length of our hope and expectation of one day housing the activities of the Institute in a group of three buildings. We believe that the useful work which the Institute is now doing and the reasonableness of our plans for work of greater and more extended usefulness will so commend the Institute as a medium to people seeking to devote some portion of their fortunes to philanthropy as to bring to our treasury the large sums necessary to the erection and support of the main building and of the scientific and technical museum, as discussed in our report of two years ago. Certainly the realization of our hopes and expectations as we have described them to you and as you have formally approved them is worthy of every effort of each of us. Let us not fail to do each his part in this great endeavor.

In this report of a year ago the Board noted the precedent established by the visit of Doctor Aston, of Cambridge University, England, who delivered a series of notable lectures under Institute auspices. During the year for which we now report, Prof. J. J. Thomson, Master of Trinity College, Cambridge, visited the Institute and delivered a series of lectures upon "The Electron in Chemistry." It is doubtful whether there has ever been delivered in this country so important a series of lectures upon a scientific subject. The hall was crowded to the limit of comfort during Professor Thomson's lectures and the attendants came from every section of the United States. Professor Thomson's auditors were experts and he spoke of them as comprising an audience of very superior interest and intelligence. We were able to arrange these lectures through the generosity of friends in the electrical industry. The success of the Institute in carrying out its plan in this respect, presenting to American scientists this series of lectures by one of the most inspiring personalities throughout the world of science, must have resulted in a notable stimulation to the scientific life of America.

The Institute is now entering upon the last year of its first century of life. Looking back over its long life we see the Institute—unaided by National, State or municipal support—giving one hundred years of efficient service in the promotion of the Mechanic Arts. Throughout the century the Institute has had one purpose and has pursued one end—the promotion of the Mechanic Arts. The work it is doing to-day is the work its founders began and the work we purpose to continue. Throughout the hundred years the Institute has had periods of prosperity and periods of depression, but never has it been without

the support of devoted men who have given of their time and money to its work. This is the example that has been set for us by four generations of men. Let us resolve that through our generation this line of honorable tradition shall continue unbroken.

Respectfully submitted,

WALTON CLARK,
President.

On motion of Doctor Alleman, duly seconded, the Board's Annual Report was unanimously approved.

The tellers of the election, Messrs. Jennings, Leffmann and Stine, reported the ballots cast for President, Vice-presidents, Treasurer and members of the Board of Managers showed the following gentlemen elected to the respective offices indicated:

W. C. L. Eglin, President (to serve one year); Gellert Alleman, Vice-president (to serve three years); C. C. Tutwiler, Vice-president (to serve two years); Benjamin Franklin, Treasurer (to serve one year); Managers to serve three years: Charles Day, Walton Clark, Charles E. Bonine, Clarence A. Hall, Lawrence T. Paul, Haseltine Smith, George A. Hoadley, James S. Rogers.

Doctor Clark said: "Seventeen years ago John Birkinbine, the then retiring President, introduced me to the membership of The Franklin Institute. And I needed to be introduced because I knew little of the Institute and less of its members. But this is not true of the newly elected President who, for a period of more than thirty years, has served the Institute in various capacities, as a member of important committees, as a representative at international conferences, as a member of our Board and as Vice-president. Seventeen years, by your favor, I have had the honour of presiding over the Institute; for seventeen years I have had contacts with science and with men of science which I could not have enjoyed had I not occupied this honourable office and my last act as your President is to me an honour indeed. It is to present to you your newly elected President, Mr. W. C. L. Eglin."

Mr. Eglin said, "Doctor Clark, Members of the Institute: I assure you first that I appreciate the honour of presiding over this great Institution as no man could occupy this position without feeling a certain sense of pleasure and personal gratification. There is a tear in our heart when I think of all of the honourable service which has been given to this Institution by the man who now in ill health has declined the nomination to this office, which he has supported not only with grace, but with great satisfaction to the membership of the Institute, and who has maintained all of its high purposes and ideals. I can assure you, gentlemen, that it has been a great pleasure and great privilege for me and for the other members of the Board who have served under Doctor Clark these many years, and if we with your help and support can maintain the high ideals and the earnestness of purpose he has shown to us, we shall have done well. Please do not expect, however, that we can do as well but we will do the best humanly possible."

The Chair then recognized Mr. Charles Day. Mr. Day said, Mr. President, Members of The Franklin Institute:

On this occasion when Dr. Walton Clark retires from the office of President, I deem it a great privilege to express, even though it must be in

terms wholly inadequate, the thoughts that so engross the minds of the Members of your Board and all his fellow workers of The Franklin Institute.

Certainly after seventeen years of unremitting effort resulting in a record of the most notable accomplishment, he should be relieved of the responsibilities attaching to the presidency. While we are most happy in the thought that his burdens will be lightened, it but tends to bring home with increasing force the full measure of what he has done for the Institute, the inspiration of his leadership and his constant devotion to its ideals and welfare. The extent of the sacrifice that this has entailed can only be appreciated when we realize that Doctor Clark has performed the work of this office while serving a great public utility corporation as one of its principal officers, with attendant heavy responsibilities and exacting duties.

Were it not for the fact that we will continue to enjoy his guidance and fullest coöperation as a member of our Board, we would indeed be overwhelmed with his retirement.

It is fitting on this occasion to record briefly the progress that has been made by The Franklin Institute during the seventeen years of Doctor Clark's administration. In all great undertakings extending over a long term of years, it is inevitable that, even though the general tendency of the quality of performance steadily improves, there will be periods when results are less favorable even to the point that the undertaking may be imperilled. It is not necessary to refer to the circumstances that were responsible for such a situation when Doctor Clark accepted the presidency. Those of us who were actively identified with its activities at that time appreciate the magnitude of the undertaking which confronted him. It matters little to which department we turn. Our physical property, whether it be our building with its equipment or our valuable collection of models, was in deplorable shape. Our financial condition was far from satisfactory. Our library, while, no doubt, our principal asset at that time and of very great value, involved a stupendous task before its fullest possibilities and usefulness could be realized.

It was inevitable that the circumstances responsible for the foregoing should result in an unsatisfactory standard of performance in connection with three of our most important functions, namely, our lecture programmes, the activities of the Science and Arts Committee, and the publication of our JOURNAL. Practically no research work was conducted under the auspices of the Institute. Its contacts with the scientific world in no degree measured up to the high standing and position which the Institute had from time to time occupied.

Such, in the briefest outline, were the conditions which Doctor Clark was required to contemplate when deciding whether he would accept the responsibilities of leadership. It was unthinkable that a man of his record of accomplishments would be satisfied with mediocre results. No one recognized so thoroughly as he the work involved in remedying the conditions to which reference has been made, and in this first decision so vital to our welfare, he was influenced by a wholly unselfish eagerness to serve; to restore that fine standing of the Institute that had marked its development in the past; to supplement his outstanding work in the field of business by the performance of real service in the interest of science and the public at large.

Having concluded that he should accept the presidency, Doctor Clark's first concern was to associate with him men particularly qualified to serve the Institute in its many and highly diversified fields of activities, whether as members of the Board or its organization. The appointment of Doctor Owens, about three years after Doctor Clark's election, marked an event of outstanding importance so well understood by our members as to require no further emphasis upon my part.

The earliest activities of Doctor Clark's administration are marked by the complete and thorough rehabilitation of our physical property, the masterful handling of our finances with a view to removing the financial limitation to the reëstablishment of a high standing in all of our activities. For the first time in many years, a thoroughly modern and effective accounting system was introduced, periodical audits by public accountants instituted and a budget system adopted. Let us not forget that in the beginning, and for a considerable period, these steps that were initiated by our President and which were so productive of splendid results in later years, were made possible only because he was constantly actuated by the conviction that if the standard of the Institute could be restored, a solution would be found to its financial problems. Many procedures were adopted that would not have been initiated except for the great faith and courage of Doctor Clark.

The briefest reference to but a few of the outstanding improvements that have been effected in our primary work will be helpful in refreshing our memory concerning the contribution made by Doctor Clark and his staff of coworkers.

Our library has been increased by more than 20,000 volumes, or by approximately one-third. All of the books, periodicals, and material of every kind have been rearranged several times with a view to ever-increasing accessibility. The indexing and cross-indexing has been completed in accordance with the most approved methods. The value of our library in its present condition can scarcely be overestimated.

The activities of the Science and Arts Committee concerning the examination of discoveries and processes in physical science and inventions have been placed upon the highest plane. The utmost care has been exercised in the appointment of the personnel of the Committee. Systematic means for the acquisition of knowledge relative to physical discovery and invention have been developed. Methods of investigation have vastly improved. The Franklin and Levy medals have been founded and the practice of affording recognition has been standardized within wise limits. To-day it may be said with confidence that no other institution of learning affords recognition to workers in physical science and technology which have a more stimulating effect or are more highly prized. Simple but impressive ceremonies now accompany the presentation of all medals and certificates.

Men of the highest standing in their respective fields comprise the lecturers at our monthly and section meetings. Those who had the pleasure of listening to Sir Joseph Thomson's farewell speech last Spring will recall that he said he had never before lectured to so brilliant an audience as that which crowded this hall on five successive days to hear what he had to say of the electron in chemistry. No other institution issues in advance a yearly programme which

contains the names of so many men preëminent in science and engineering who can treat authoritatively matters of prime interest and importance in this industrial era, when the experiment of to-day may to-morrow prove to be of outstanding importance in the largest sense.

THE FRANKLIN INSTITUTE JOURNAL stands in a class by itself. Its pages contain information not only of immediate interest but of lasting value, both to the scientist and to the engineer.

Finally, while the work of the Institute throughout the past hundred years has consisted mainly of *encouraging* research and invention, *disseminating* useful scientific and technical information and making contacts between the man of pure science and the man engaged in industry, it has ever looked forward to the time when, with adequate laboratories and a highly trained staff, additions of a substantial kind might be made through its own efforts to the already great sum of scientific knowledge which forms the ground work of modern civilization. This long-looked-for opportunity has come through the munificent bequest of one of our distinguished former members, the late Henry W. Bartol. There is no work in which Doctor Clark has been more deeply interested or to which he has made a more important personal contribution than in the establishment of The Bartol Research Foundation of The Franklin Institute. Laboratories have been completed and will be equipped soon. Of course, results such as Faraday obtained in the Royal Institution, can be expected only if supreme wisdom is shown in the selection of the staff. Every possible care is being exercised and we sincerely hope that in the not distant future The Franklin Institute will be possessed of productive laboratories that will achieve a position of international importance in the field of science.

It is particularly gratifying to those of us who have been so closely associated for many years with Doctor Clark to know that his retirement should be coincident with the completion of preparatory work relative to this Foundation which we have every reason to believe marks the beginning of a service of The Franklin Institute second to none in its long career.

As already stated, it is most fortunate that not the least of Doctor Clark's accomplishments has been concerned with the organization of the work and business of the Institute upon a sound basis and the creation of a devoted personnel that assures a continuance of an unparalleled standard in our particular field of service under the leadership of our incoming President, Mr. W. C. L. Eglin, who is so splendidly qualified for the post. We derive the greatest satisfaction from the knowledge that there will be no break in the work which Doctor Clark has carried forward to this point, but this cannot lessen our feeling of loss through his retirement. Such unselfish devotion in the interest of science as has marked the past seventeen years of his association with the Institute calls forth the admiration and high regard of a great group of people, but it has been our special privilege to come to know and value even more highly his unaffected modesty, kindliness of spirit and capacity for genuine, lasting friendship.

The Chairman said:

You have heard the statement of Mr. Day, our Vice-president, expressing the sentiment of the Board of Managers, and of all those active in the affairs of the Institute relative to the splendid work of Doctor Clark done here during

the past seventeen years. It is the only way we have of showing honour to our retiring President.

Mr. Walton Forstall moved that Mr. Day's remarks be spread on the minutes. This was duly seconded and passed unanimously.

The Chairman then said:

The lecturer of the evening, Charles H. Herty, Ph.D., D.Sc., President, Synthetic Organic Chemical Manufacturing Association, New York City, will now present his paper on "The Coal-tar Industries of the United States."

Doctor Herty said:

Mr. President, Members of the Institute, and friends: Before beginning my paper I want to express to you my very deep appreciation of the honour I feel it is to be invited to lecture here again. I am indebted to you for an evening spent with you eight years ago, at which time I was a guest of The Franklin Institute and spoke upon a similar subject. I look back to that evening with the keenest delight. I have given addresses in every section of the country on one subject or another and have always enjoyed it, but somehow there was a warm relationship immediately established between the audience and myself at the Institute on the evening I spoke of, which for me was a wonderful inspiration, and so I come back to you happy in the thought of that meeting and deeply appreciative of the fact that after having me once you were willing to invite me again.

I want also to express my admiration for the Institute and to congratulate it upon the completion of one hundred years of useful service to science in this country. It has been my good fortune to be a member of the Institute for a number of years and I realize what a tremendous stimulus it has been to science. I feel that Philadelphia has become a real home of science, prompted by an institution of this kind. I think you have good cause for being happy over a century of useful service.

Doctor Herty then read his paper on "The Coal-tar Industries of the United States."

He pointed out that the United States possess an abundance of raw materials for the development of the coal-tar industries, but prior to the war world economic conditions were such that a large proportion of the coal-tar was wasted or consumed in the raw state. War conditions brought about a blockade against German coal-tar chemicals, and this in turn led to the development of a coal-tar chemical industry in this country. Dyestuffs, medicinals, high explosives, photographic chemicals, synthetic flavoring extracts, perfumes and tanning materials are all finished products emanating from coal-tar. During the past five years the coal-tar chemical industry has grown to an annual production of eighty-eight million pounds, of a total value of fifty-four million dollars, as shown by the United States Tariff Commission annual census.

From an economic point of view it is essential that the independence of this country in this line of manufacture should be maintained. The industry is a national asset of vital significance from the standpoint of security, of health, and of economics.

On motion of Doctor Taggart, a rising vote of thanks was extended to the speaker, and the meeting adjourned.

R. B. OWENS,
Secretary.

WALTON CLARK.

WALTON CLARK was born in Utica, N. Y., April 15, 1856, son of Erastus and Francis B. (Beardsley) Clark. The Clark family is of English ancestry, the American branch being founded in 1639 by Daniel Clark, of Weaxil, England.

Mr. Clark was educated in the public schools of Utica. At the age of seventeen years he became associated with a gas-producing company in New Orleans, La., going to Chicago, Ill., in 1887, where he was engaged in the same line of work, and to Kansas City in 1888. The same year he removed to Philadelphia to accept a position with The United Gas Improvement Company, subsequently advancing to the position of Vice-president of that company.

In 1904 the Stevens Institute of Technology conferred upon him the honorary degree of M. E., and in 1911 the University of Pennsylvania conferred upon him the honorary degree of Doctor of Science.

Mr. Clark was elected President of The Franklin Institute of the State of Pennsylvania in 1907, and continued in the presidency for seventeen years.

He has served as President and Director of various companies engaged in public utility work. He was at one time President of the American Gas Light Association, and later of the American Gas Institute. He is a member of the American Society of Mechanical Engineers, the American Institute of Electrical Engineers and the American Institute of Mining and Metallurgical Engineers, and other scientific bodies. He has been a member of the board of trustees of several educational institutions. He was active in the organization of a free correspondence school for gas works employees, and was chairman of its Board of Trustees for twenty-five years.

He is a member of the Union League, University Club, Rittenhouse Club, Engineers Club, Merion Cricket Club, Philadelphia Cricket Club, Whitemarsh Valley Country Club, Sunnybrook Golf Club of Philadelphia, and of the Engineers Club of New York. He is a member of the Society of the Cincinnati and of the Founders and Patriots Society.

On December 28, 1880, Mr. Clark married (first) Alice M. Shaw, daughter of Colonel H. B. and Mary (Latimer) Shaw, of Natchez, Miss., who died in 1882. Mr. Clark married (second), in 1885, Louise Beauvais, daughter of Pierre Ernest Beauvais and Palmyre Marcelline Nicholas, his wife, and an adopted daughter of Rufus King Cutler and Marie Palmyre Beauvais, his wife, of New Orleans, La.

Children of Walton Clark: 1. Frank Shaw, married Marie DeRossett. 2. Walton, Jr., married Elizabeth (Depuy) Scott, and their children are Elizabeth Scott and Edith Graham. 3. Theobald Forstall, married (first) Grace Tetlow, and their son is Theobald F., Jr.; married (second) Dorothy Nevin, and their sons are Edward Ogden and Anthony Morris. 4. Beauvais. 5. Darthela.

DR. WALTON CLARK.
Retiring President of The Franklin Institute.

W. C. L. EGLIN.

MR. WILLIAM C. L. EGLIN, President of the Institute, was born in Scotland in 1870, educated in the Andersonian University and the University of Glasgow. In 1889 he became connected with the engineering department of the Edison Light Company of Philadelphia and was advanced to the position of Chief Engineer. He is at present Vice-president in charge of Engineering of The Philadelphia Electric Company. In 1896 twenty-six independent electric companies operating in Philadelphia were consolidated and a large part of effecting this consolidation, which involved much work in standardizing the generating and distribution systems, devolved upon Mr. Eglin, who took especial charge of the designing and construction of the sub-stations. The several operating companies thus combined presented a great variety of equipment and output employing a wide range of pressures, phases and frequency. Out of all this variety he developed The Philadelphia Electric Company's uniform sixty-cycle alternating current system. As part of this work he was among the first to install sixty-cycle rotary convertors in commercial service in the United States. The widespread use of this at the present time demonstrates Mr. Eglin's practical ability. He also was an early employer of the oil-break switch, one of which was designed and built under his direction. This type of switch is essential to the successful operation of modern control systems. In 1916, 1917 and 1918 Mr. Eglin had charge of the design and construction of The Philadelphia Electric Company's plant, built at Chester on the Delaware River, and also charge of the design and construction of another large plant of the Company at Beach and Palmer Streets, Philadelphia, which when completed will have an ultimate capacity of 240,000 H.P. During his term of service as Chief Engineer the capacity of the Company has increased from 10,000 k.w. H.P. to upwards of 350,000 k.w. H.P., thereby ranking the Philadelphia installation among the largest central station systems in the world. Upon the entrance of the United States into the war, Mr. Eglin gave personal attention to meeting the power requirements of the large shipbuilding and other rapidly developing war industries in the metropolitan district of Philadelphia which were of the greatest importance to the nation.

In the midst of these active and laborious services Mr. Eglin has not neglected attention to professional organizations, being a past President of the National Electric Light Association and a Fellow of the American Institute of Electrical Engineers. For a number of years he was active in the management of the Engineers Club of Philadelphia, for which he served as representative at the International Engineering Congress held in Paris in 1900, and also as representative of The Franklin Institute. His contributions to the literature of electrical engineering have been numerous and valuable.

W. C. L. EGLIN.

Newly Elected President of The Franklin Institute.

COMMITTEE ON SCIENCE AND THE ARTS.

(Abstract of Proceedings of Stated Meeting held Wednesday, January 2, 1924.)

HALL OF THE INSTITUTE,
PHILADELPHIA, January 2, 1924.

MR. W. H. FULWEILER, *in the Chair.*

The following reports were presented for final action:

No. 2799: Gear Tooth Grinding Machine. Final action was deferred until the February meeting.

No. 2814: Elliott Deaerator. The Edward Longstreth Medal to William Swan Elliott, Esq., of Pittsburgh, Pennsylvania.

No. 2819: The Franklin Medal to Dr. Edward Weston, President of the Weston Electrical Instrument Company, Newark, New Jersey, "In recognition of discoveries and inventions in the field of electricity, fundamentally contributing to the establishment of the electric art."

No. 2820: The Franklin Medal to Sir Ernest Rutherford, Cavendish Professor of Experimental Physics, the University of Cambridge, Cambridge, England, "In recognition of successful researches, signally contributing to the present state of knowledge of the elements, their constitution and relationships."

The Committee having in charge the investigation of the Elliott Deaerator reported in part as follows:

The Elliott Deaerator was designed to provide means for the removal of oxygen and other dissolved non-condensable gases from boiler feed-water to minimize pitting and corrosion of boilers, economizers and pipe lines.

Corrosion is especially troublesome in high-pressure piping and boilers, where an overload of 200 or 300 per cent. is carried. The present-day tendency in steam plants is to operate the boilers at a very high rating. The use of high pressures imposes a high exit flue gas temperature, making the use of an economizer for further heat recovery very desirable.

Where steel tube economizers have been operated without the Elliott apparatus serious corrosion difficulties have been encountered.

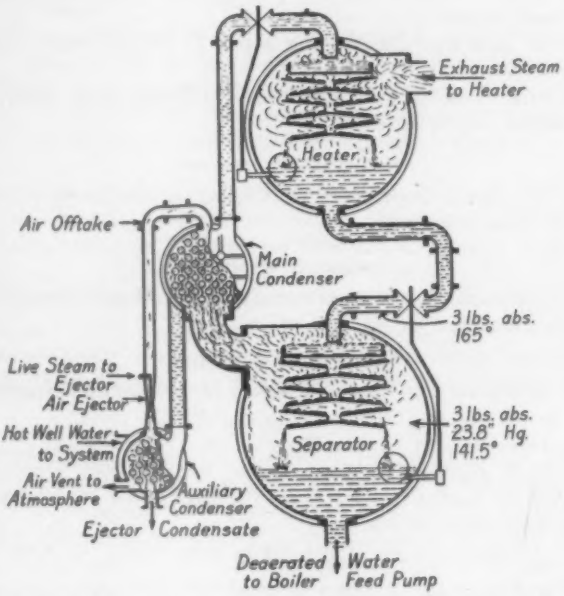
The use of high pressures has brought steel tube economizers into wide use. Without the protection of deaeration the steel tube has a useful life so short that it does not constitute a profitable investment.

The Elliott Deaerator is a flexible apparatus and may be arranged to meet conditions existing in various plants. It may take the place of the usual open feed-water heater and perform the same functions.

The operation of one arrangement of the deaerator may be described by reference to the sketch shown herewith. Water is drawn from the supply line or hot well and circulated through the tubes of the auxiliary and main condensers of the deaerator which are connected in series. It then flows into the feed-water heater where it is heated to the desired temperature by exhaust steam. The heated water flows into the separator, which is under partial vacuum, and this vacuum is maintained at such a point that the temperature corresponding to the vapor pressure is usually about twenty-five degrees lower than that of

the entering water. The drop in temperature of the inlet water releases latent heat and a portion of the water flashes into steam, at the same time releasing the dissolved gases. The water cascades over the trays and falls into the lower part of the separator and is pumped off to the boilers, economizers or service lines. The vapor and liberated gases are carried off through the

FIG. 1.



condenser where the vapor is condensed and flows back into the system, the non-condensable gases being expelled by the air ejector, and the steam used in the ejector is condensed in the auxiliary condenser.

This apparatus has been found highly satisfactory as it almost completely removes the non-condensable gases from feed-water and has for practical purposes solved the rust-prevention problem. The introduction of this invention in the large steam power plants throughout the country, making practicable the use of the steel tube economizer, marks a new era in boiler operation.

The conclusion of the report on this investigation on which the award was made is as follows: "In consideration of his notable achievement in the scientific and commercial development of a method and apparatus for the successful deaeration of feed-water for use in power plants, the committee recommends the award of the Edward Longstreth Medal to William Swan Elliott, Esq., of Pittsburgh, Pennsylvania, for the Elliott Deaerator."

The Franklin Medals with accompanying certificates will be presented on the afternoon of Wednesday, May 21, next.

R. B. OWENS,
Secretary.

MEMBERSHIP NOTES.

ELECTIONS TO MEMBERSHIP.

(Stated Meeting, Board of Managers, January 9, 1924.)

RESIDENT MEMBERS.

MR. CYRUS N. ANDERSON, Patent Lawyer, 519 Land Title Building, Philadelphia, Pennsylvania.

DR. ELBERT C. LATHROP, Chemist, 210 South Thirteenth Street, Philadelphia, Pennsylvania.

MR. ALEXANDER WILSON, 3rd, Mechanical Engineer, 1000 Chestnut Street, Philadelphia, Pennsylvania.

NON-RESIDENT MEMBERS.

DR. J. H. MATHEWS, Department of Chemistry, University of Wisconsin, Madison, Wisconsin.

ASSOCIATE MEMBERS.

MR. CARROL BERNARD NEBLETTE, Editor, 636 South Franklin Square, Philadelphia, Pennsylvania.

CHANGES OF ADDRESS.

MR. A. W. K. BILLINGS, in care of Brazilian Hydro-electric Company, Limited, Caixa de Correio 2444, Rio De Janeiro, Brazil.

MR. W. L. DEMPSEY, 305 Granite Building, St. Louis, Missouri.

MR. CHARLES N. FORREST, 175 Elm Avenue, Rahway, New Jersey.

MR. THEODORE F. JENKINS, 1100 Liberty Building, Broad and Chestnut Streets, Philadelphia, Pennsylvania.

COLONEL P. JUNKERSFELD, 68 Trinity Place, New York City, New York.

NECROLOGY.

Mr. Morris L. Orum, 1320 North Nineteenth Street, Philadelphia, Pennsylvania.

PUBLICATIONS RECEIVED.

Chemisch-Technische Vorschriften. Ein Handbuch der speziellen chemischen Technologie von Dr. Otto Lange. III Band: Harze, Öle, Fette. 796 pages, 8vo. Leipzig, Otto Spamer, 1923. Price, in paper, 45 gold marks.

Systematic Survey of Rubber Chemistry. A bibliography, with copious abstracts, of the entire literature of rubber chemistry and closely allied subjects. By Clayton W. Bedford and Herbert A. Winkelmann. 385 pages, 8vo. New York, The Chemical Catalog Company, 1923. Price, $7.

Radioactivity and the Latest Developments in the Study of Chemical Elements. By K. Fajans, translated from the fourth German edition by T. S. Wheeler and W. G. King. 138 pages, illustrations, 12mo. New York, E. P. Dutton and Company, 1923. Price, $3 50.

Einleitung in die Mengenlehre. Eine elementare Einführung in das Reich des Unendlichgrossen von Adolf Fraenkel. Second revised edition, 251 pages, illustrations, 8vo. Berlin, Julius Springer, 1923.

Traité du Calcul des Probabilités et de ses Applications. Par Émile Borel. Tome III. Les applications de la théorie des probabilités aux sciences économiques et biologiques. Fascicule 1 Assurances sur la vie calcul des primes par Henri Galbrun. 312 pages, 8vo. Paris, Gauthier-Villars et Cie., 1924. Price, in paper, 35 Francs.

Applications numériques de la nouvelle méthode de Calcul des grandes Constructions continues. Par Auguste Liévin. 144 pages, illustrations, 8vo. Paris, Le Constructeur de Ciment Armé, 1923. Price, in paper, 18 Francs.

Influence du Système de Triangulation sur les Efforts Secondaires. Par Z. Bazant. 50 pages, illustrations, 8vo. Prague, Masarykova Academie Práce, 1923.

National Advisory Committee for Aeronautics: Technical Notes, No. 170, Reduction in Efficiency of Propellers due to Slipstream, by Max M. Munk. 6 pages, quarto. No. 171, Compressive Strength of Tapered Airplane Struts, by Victor Lewe. 7 pages, diagram, quarto. No. 172, The Nichols Wing Cutting Equipment, by James B. Ford. 6 pages, photographs, quarto. No. 173, Significance of the Expression C_L^3/C_D^2, by H. von Sanden. 4 pages, quarto. Eighth Annual Report of the Committee for 1922 including Technical Reports, Nos. 133 to 158. 708 pages, illustrations, plates, diagrams, quarto. Washington, Committee, 1923–1924.

Standardization in Germany.—The American Engineering Standards Committee has just issued a bulletin giving data in regard to the great progress that has lately been made in Germany to standardize the many industries. As with most German operations, these methods have been widely and concertedly carried out. Instances are given from the report of Dr. P. G. Agnew, secretary of the committee, who recently returned from Europe, having been for two months engaged in studying the conditions and the manner in which European development of standardization is likely to affect American industries.

Practically every important manufacturing concern in Germany is officially participating in the industrial standardization program of that country. More than a thousand German companies have formal standardization organizations within their own works. These organizations are called "standards bureaus." The larger firms have branch bureaus in the separate departments, or in the separate factories. One of the well-known companies has twenty-one such branch bureaus, employing in all a special staff of more than one hundred. Another firm has a permanent full-time staff of over two hundred in its various branch bureaus. In all of the great firms the bureau reports directly to the general manager.

The extent to which industrial life in Germany has been coördinated, it is stated, is shown by the fact that more than seven hundred German national standards have been adopted. This includes only